CALIFORNIA FISH AND GAME

"CONSERVATION OF WILDLIFE THROUGH EDUCATION"

VOLUME 64 OCTOBER 1978 NUMBER 4

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CALIFORNIA FISH AND GAME

VOLUME 64 OCTOBER 1978 NUMBER 4

Published Quarterly by

STATE OF CALIFORNIA

THE RESOURCES AGENCY

DEPARTMENT OF FISH AND GAME

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NORTHERN CALIFORNIA DUNGENESS CRAB, *Cancer magister*, MOVEMENTS AS SHOWN BY TAGGING [1]

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From 1956 through 1967, 6,209 male Dungeness crabs were tagged and released off northern California from Usal to Pelican Bay. A total of 1,434 tags was returned, 1,073 with catch data. Two hundred four (19%) of the returnees with catch data came from within 1.8 km (1 mile) of the release area. The populations of juvenile and adult Dungeness crabs appear to be discrete in the areas between Fort Bragg and Cape Mendocino and False Cape to Pelican Bay. Generalized movement models are proposed for crabs tagged between Fort Bragg and Cape Mendocino; False Cape and the Klamath River; Klamath River and Brookings, Oregon.

INTRODUCTION

Intermittent tagging studies of Dungeness crabs have been conducted off northern California since 1956. Two of the studies off the northern coast were reported by Jow (1960, 1965). These tagging studies were conducted to determine movements and rates of survival, growth, and exploitation.

The tagging studies reported here were conducted in 1956, 1958, 1962, and 1964–67 on male crabs from Usal north to the Oregon border (Figure 1). The results (including data from Jow's tagging operations) are presented in terms of movement behavior and stock definition.

METHODS

Three kinds of tags were used: plastic Peterson discs, stainless steel straps, and suture tags. Peterson disc tags were used in 1956, 1962, and to some extent during 1964 and 1965. In addition, during the 1956 study, several hundred crabs were tagged with stainless steel strap tags. These tags consisted of a piece of stainless steel plate 0.02 x 1.3 x 5.1 cm (0.008 x 0.5 x 2.0 inches) attached to the lateral spines by stainless steel wire loops. Some crabs were tagged with both Peterson discs as well as the strap tags to compare shedding rates. It was hoped that fishermen would notice the strap tag more readily than the Peterson discs. Suture tags were used in 1958, 1964, 1965, 1966, and 1967 studies (Butler 1957; Snow and Wagner 1965). Crabs were captured with standard commercial type traps or otter trawls fished from Department of Fish and Game research vessels. Records were kept of size and shell condition of each crab tagged.

Recovery data were divided into two categories: crabs that remained within a 1.6-km (1-mile) radius of release site, and crabs that moved from the release area. Crabs which moved from the release area were grouped by 30-day intervals of days at liberty. The movements for each 30-day interval were collated into kilometers of movement north or south and inshore or offshore movement from the release site.

[1] Accepted for publication October 1977.

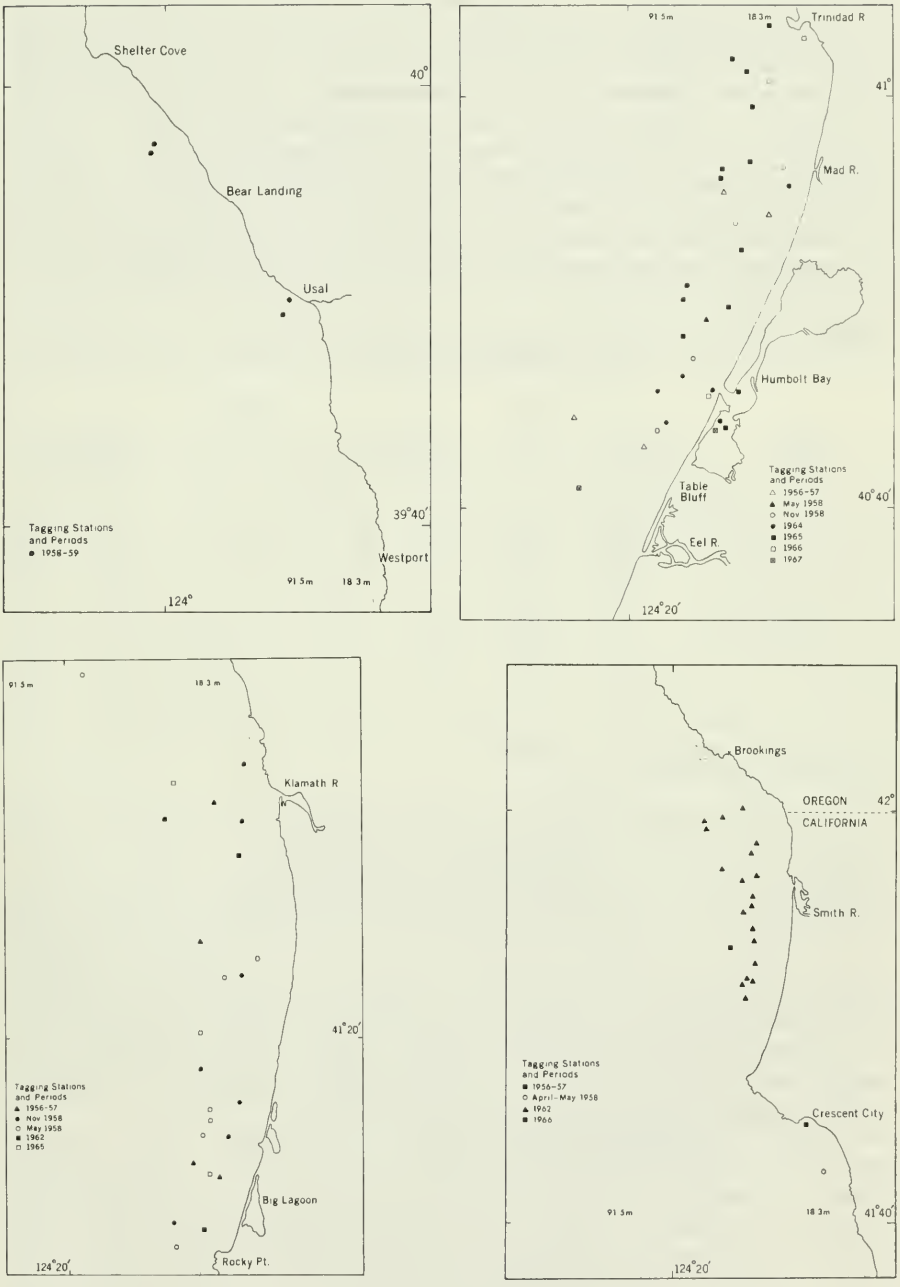

FIGURE 1. Tagged Dungeness crab release sites. Upper left: Usal to Shelter Cove, 1958; Upper right: Eel River to Trinidad, 1956 to 1967; Lower left: Rocky Point to Klamath River, 1956 to 1965; Lower right: Crescent City to Brookings, Oregon, 1956 to 1966.

RESULTS

1956

A total of 705 legal sized male crabs (159 mm [6.25 inches] carapace width or larger) was released in the area between False Cape and the California-Oregon border in autumn (Table 1). Peterson discs were used on 237 crabs, strap tags on 235 crabs, and 239 crabs were tagged with both types. Of the 227 tagged crabs recovered, 65 were Peterson disc tagged, 69 had strap tags, and 67 carried both tags. In addition, 18 crabs were captured that had been double tagged originally but on which only the Peterson disc remained; and 8 were recovered with only the strap tag intact. Both tag types were subject to loss; however, fishermen did report taking off one of the tags and re-releasing some of the crabs.

TABLE 1. Number of Tagged Dungeness Crabs Released and Recovered off Northern California, 1956–1967. *

Tagging dates	*Number released*	*Release depth range (m)*	*Crabs recovered*		*Recoveries with catch data*		*Recovered in release area*	
			No.	*%*	*No.*	*%*	*No.*	*%*
Nov. 1956	705	22–55	227	32.2	201	88.5	13	35.8
Apr. to Dec. 1958	2,079**	18–66	401	19.3	151	37.6	12	7.9
Nov. to Dec. 1962	901	18–33	531	58.9	471	88.7	169	35.8
Oct. 1964 to June 1965	1,022	2–55	144	14.1	137	95.1	6	4.4
July 1965 to Feb. 1966	348	11–58	29	8.3	24	82.8	0	0.0
Nov. 1966 to June 1967	1,109	4–46	100	9.0	87	87.0	4	4.5
July to Nov. 1967	45		2		2		0	
TOTAL	6,209	4–66	1,434	23.0	1,073	74.8	204	19.0

* Includes data from Jow's studies (1960 and 1965).
** 453 released in April and May.

Catch data are available for 201 of the recoveries. Twelve (6%) of the recovered crabs were captured within the release area.

Sixty-nine (76%) of the crabs originally released in the area between the Eel River and Mad River were recovered north of their release sites (Figures 1 and 2). Two crabs had not moved either north or south, and the remaining 20 moved south. The average northerly movement was 54 km (32.4 miles), the average southerly movement, 14.8 (9.2 miles). No southerly movement was recorded after 150 days at liberty. Sixty-seven (74%) of the recoveries were closer to shore than their release point. The change in depth for crabs moving inshore ranged from 2 to 48 m (1 to 26 fm). For crabs moving offshore the change in depth ranged between 2 and 16 m (1 and 9 fm).

Sixty-one crabs originally released between Rocky Point and the Klamath River were recovered: 54 (88%) of them during the 1956–57 season and the remainder during the 1957–58 season. Only 9 (8%) of the crabs were recovered south of their release site (Figures 1 and 3). The average southerly movement was 17.7 km (11 miles). The average northerly movement was 41 km (25.5 miles) for crabs recovered during the 1956–57 season. Forty-five of the crabs recovered during the 1956–57 season moved inshore; the range in depth change

was 6 to 38 m (4 to 21 fm). Northerly movements for six crabs recovered during the 1957–58 season averaged 41.5 km (25.8 miles). One crab moved 26 km (16 miles) south. Five of the recovered crabs had usable catch data and had moved inshore; the range in depth change was 16 to 35 m (9 to 19 fm). Depth recovery could not be determined for seven returns in the 1956–57 season and three returns in the 1957–58 season.

Recovery data from crabs released between Crescent City and Brookings, Oregon (Pelican Bay) yielded contrasting results (Figures 1 and 4). Only seven of 45 recoveries (16%) during the 1956–57 fishing season were from north of the release site. The average northerly movement was 0.1 km (0.4 miles). The average southerly movement was 30.6 km (19 miles) for 38 recoveries. Only one crab was recovered during the 1957–58 season, 64 km (40 miles) north of the release area. All but one of the crabs were recovered inshore of the original release depth. The change in depth for inshore movements ranged from 2 to 22 m (1 to 12 fm).

1958

During 1958, 2,079 crabs were tagged and released between Fort Bragg and Crescent City (Table 1, Figure 1); 453 (326 sublegal and 127 legal sized) were tagged and released during April and May, the remaining 1,626 during November and December. The latter were all legal sized. Of 401 recoveries, 151 (38%) were returned with catch data, and 32 (8%) of these were recovered within 1.6 km (1 mile) of the release site.

Of the 897 crabs released in the Usal to Shelter Cove area in November and December, slightly more than one half (31) of the total recoveries (54) came from south of their release sites. Most recoveries occurred during the 1958–59 season. Twenty-four crabs moved an average of 12.9 km (8 miles) south and 23 crabs moved an average of 10.5 km (6.5 miles) north (Figure 5). Five crabs moved either inshore or offshore with no corresponding north or south movement. Two crabs were recovered during the 1959–60 season, one had moved 11 km (7 miles) north, the other, 6 km (4 miles) south. Eight crabs were recovered inshore of the release site and 38 offshore. The change in depth for inshore recoveries ranged from 1.8 to 7.3 m (1 to 4 fm); offshore depths ranged from 2 to 24 m (1 to 13 fm). None of the 64 crabs released in this area during May was recovered.

Four hundred ninety-three tagged crabs were released between Table Bluff and Trinidad; 193 during April and May, the remaining 300 during November and December. None of the crabs released between Table Bluff and Trinidad during April and May was recovered during the 1957–58 fishing season. Six were recovered during the 1958–59 season; four of these moved an average of 60.4 km (37.5 miles) north. Two crabs moved an average of 18.5 km (11.5 miles) south. Four crabs were recovered inshore from the release depths. The change in depth ranged from 6 to 13 m (3 to 7 fm). Thirty crabs released during November and December were recovered with catch information; all recoveries were made during the 1958–59 fishing season. One crab moved inshore but the north/south movement could not be determined from the catch data, and one crab moved inshore with no corresponding north or south movement. Nineteen (63%) came from north of the release sites. Eight were recovered south of the release sites. The average northern movement was 41.2 km (25.6 miles); the average southerly movement was 9.2 km (5.6 miles). Eighteen (70%) of the

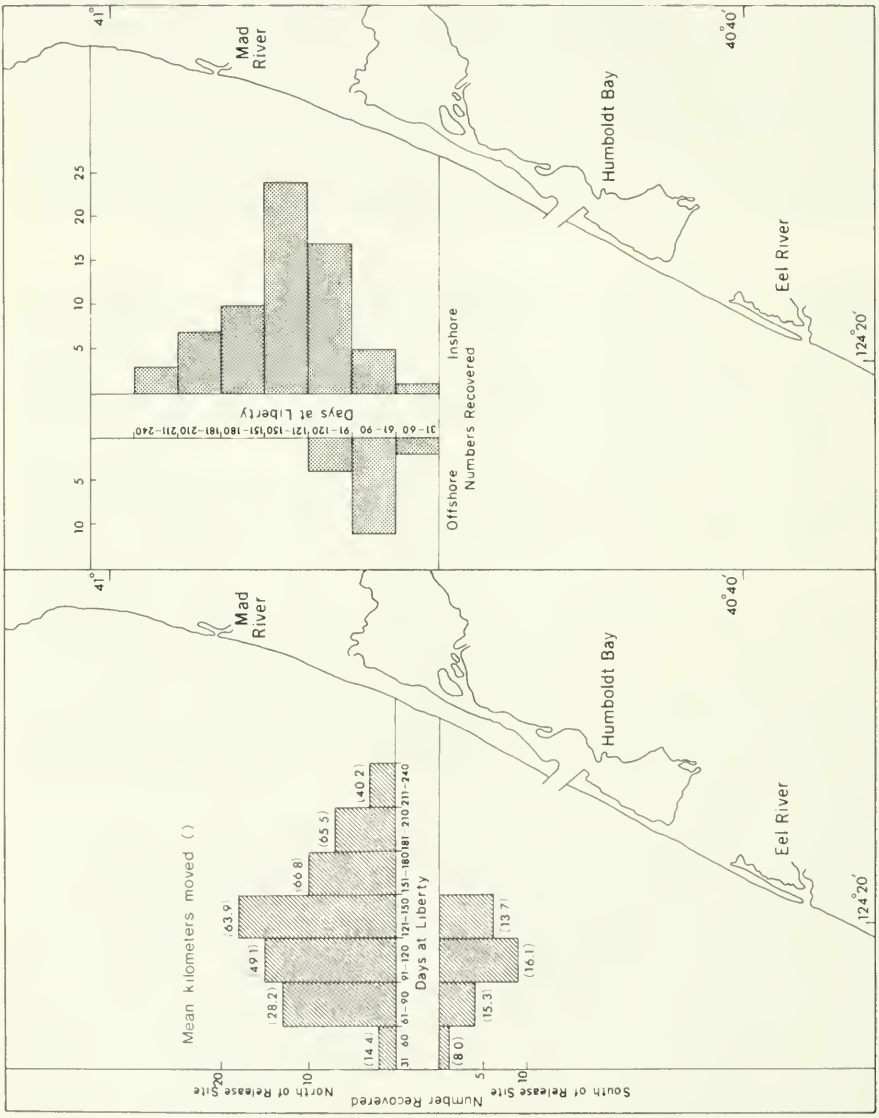

FIGURE 2. Recovery data for tagged Dungeness crabs released between the Eel River and Mad River, 1956.

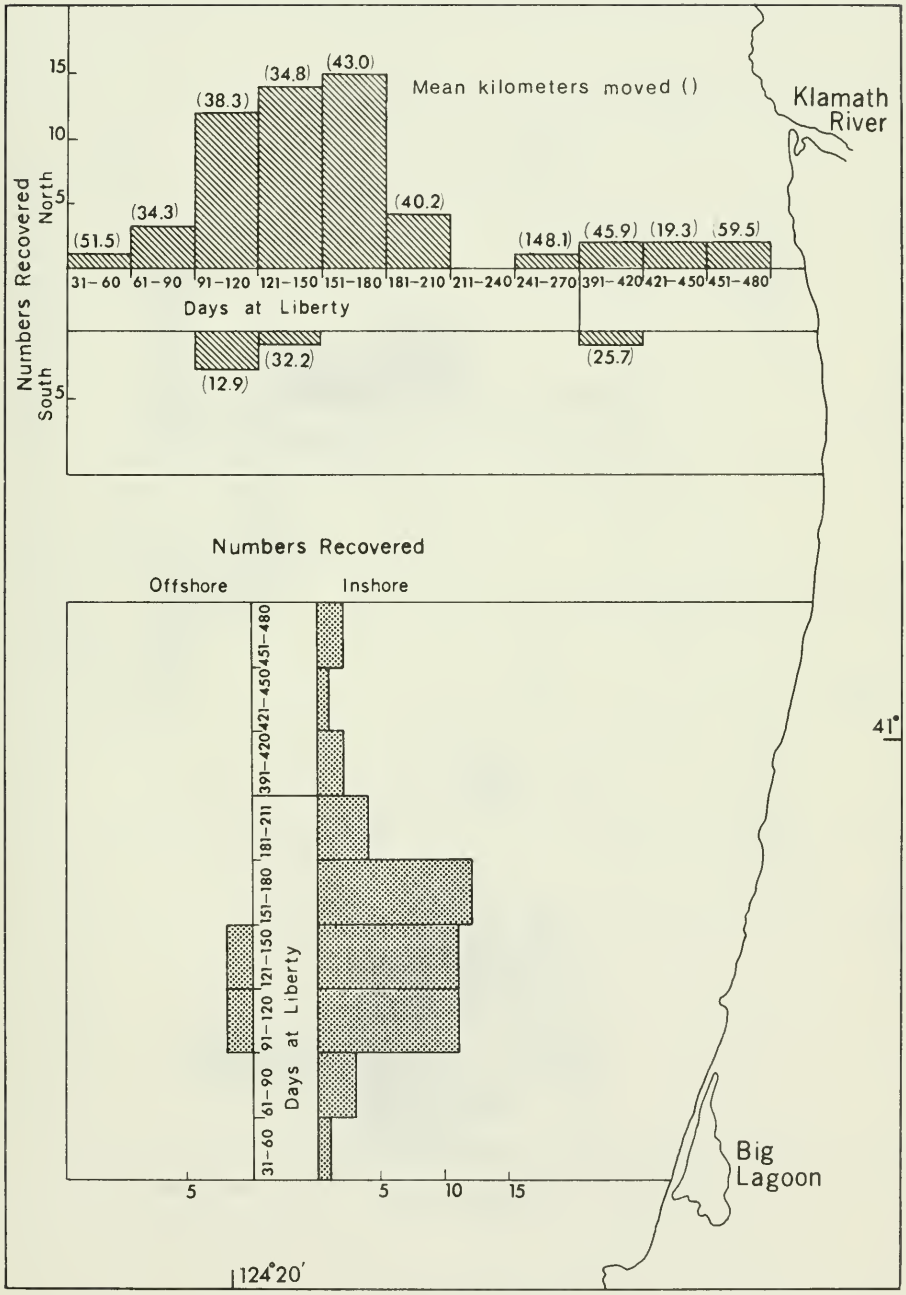

FIGURE 3. Recovery data for tagged Dungeness crabs released between the Big Lagoon and Klamath River, 1956.

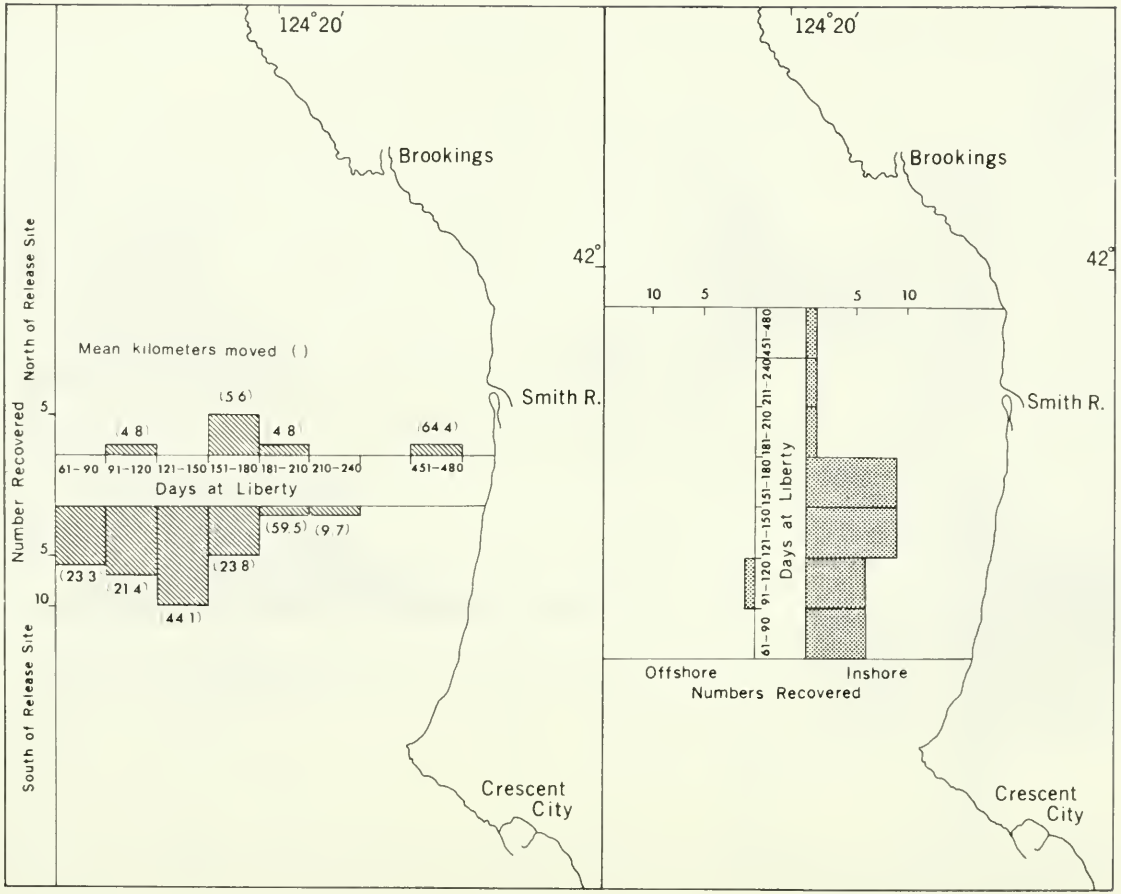

FIGURE 4.—Recovery data for tagged Dungeness crabs released in Pelican Bay, 1956.

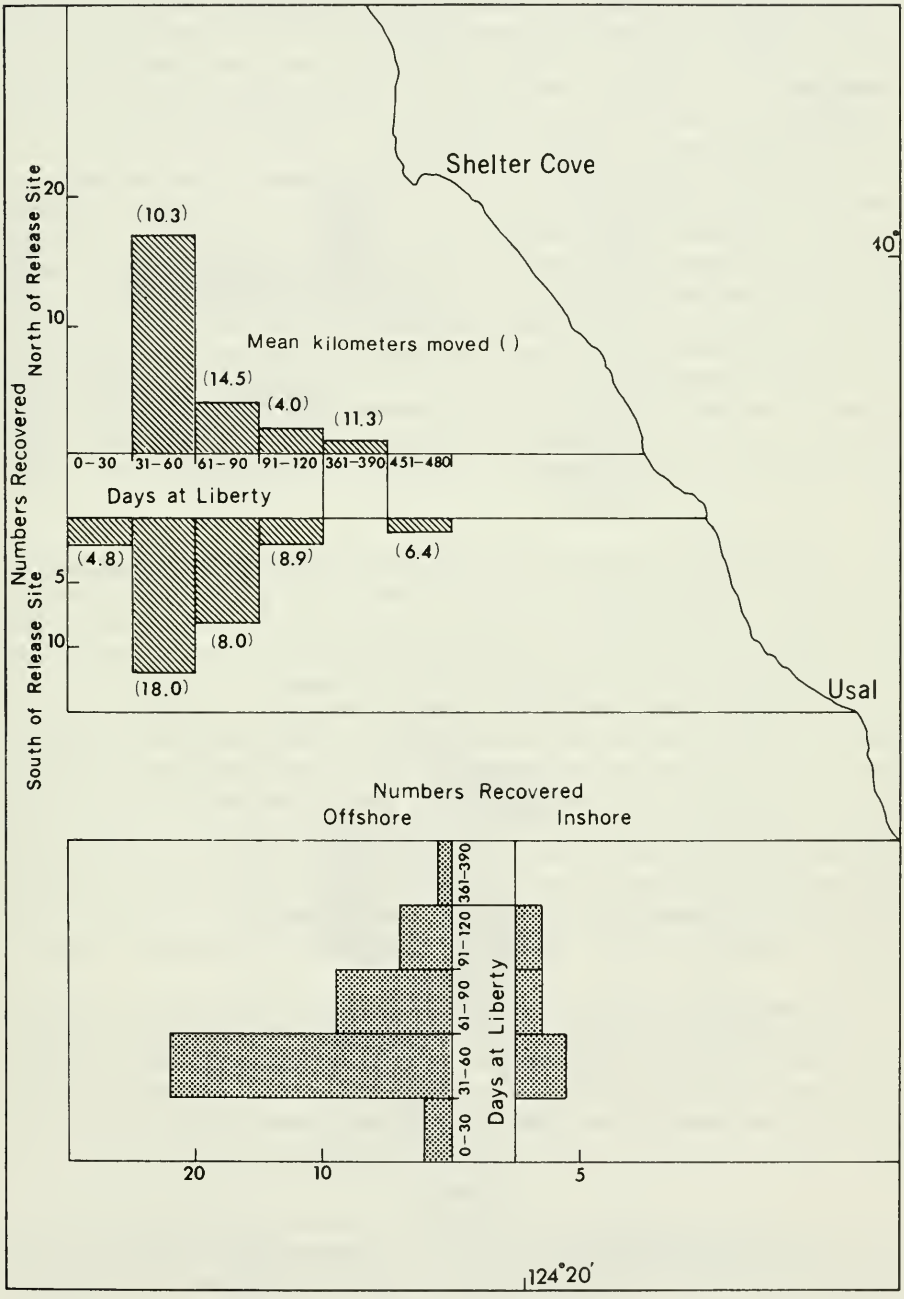

FIGURE 5. Recovery data for tagged Dungeness crabs released between Usal and Shelter Cove, 1958.

crabs moved inshore from the release depths; six of the recoveries lacked depth of recovery data. Inshore movement ranged from 2 to 35 m (1 to 19 fm).

Nine of 119 crabs tagged and released between Big Lagoon and Crescent City during April and May were recovered during the 1957–58 fishing season. Eight moved north an average of 7.4 km (4.6 miles) and one moved south 9.6 km (6 miles). One crab was recovered during the 1958–59 fishing season 40 km (25 miles) south of the release site. All of the crabs with depth of recovery data moved inshore from 11 to 48 m (6 to 26 fm).

Thirty-nine recoveries from 376 tagged crabs released in the area between Patrick's Point and the Klamath River mouth during November and December showed a different pattern than did the 1956–57 recoveries from this area (Figure 6). Twenty (50%) compared to nine (8%) during the 1956–57 study were recovered south of the release sites. The average southerly movement was 27 km (16.8 miles). The 18 crabs that moved north averaged 27.2 km (16.9 miles). Inshore-offshore movements, however, did show similar results for the two recovery periods. Most crabs were recovered inshore. Recovery depths could not be determined for five crabs. Offshore depth changes ranged from 2 to 7 m (1 to 4 fm); inshore depth changes from 2 to 43 m (1 to 24 fm). None of the 141 crabs released between the Klamath River and Pelican Bay during April and May was recovered.

1962

A total of 901 legal sized crabs was released during November and December 1962, 825 in Pelican Bay and 76 off the Klamath River (Figure 1). Three hundred twenty-two crabs (36%) were recovered within 1.6 km (1 mile) of the release site. Data from 282 recovered crabs released in Pelican Bay and 30 released off the Klamath River were sufficient to study movement.

Twenty-eight (10%) Pelican Bay tagged crabs were recovered during the 1962–63 fishing season and had moved inshore or offshore with no corresponding north or south movement. One hundred eighteen (42%) were recovered an average distance of 6.9 km (4.3 miles) north of the release sites, and 127 (45%) an average distance of 11.7 km (7.3 miles) south of the release sites (Figure 7). One crab that moved 10 km (6 miles) south was recovered during the 1963–64 fishing season. One hundred sixty-seven crabs (86%) moved inshore from the release depths; these movements ranged from 2 to 25 m (1 to 14 fm). Eighty-eight crabs were recovered with incomplete depth of recovery data.

The crabs released off the Klamath River showed a stronger tendency to move south; 19 (63%) were recovered south of their release sites an average distance of 13.2 km (8.2 miles). Nine crabs moved north an average distance of 8.7 km (5.4 miles). Two moved inshore of the release site with no corresponding north or south movement. The two offshore movements were limited to the first 30 days at liberty. Twenty-three crabs moved inshore from 3 to 21 m (2 to 12 fm).

1964–65

From October 1964 through June 1965, we released 383 sublegal and 64 legal sized crabs inside Humboldt Bay. Ten were recovered, four inside the Bay and six outside (Table 2). Eighty-four (17%) of the 487 sublegals and 52 (60%) of the 88 legal sized crabs released outside the Bay were recovered, none inside the Bay. No sublegal sized crabs recovered during the 1964–65 season had

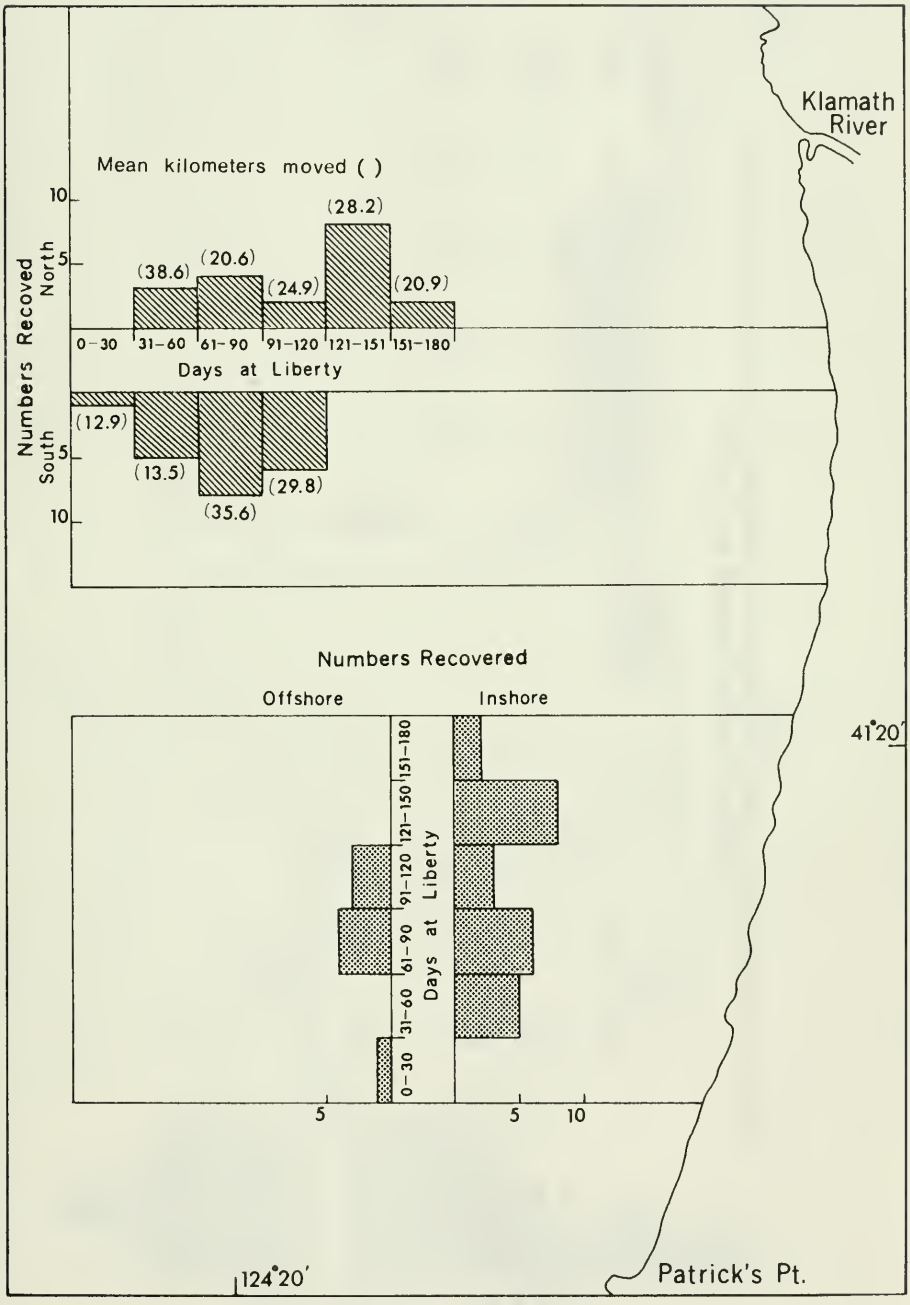

FIGURE 6. Recovery data for tagged Dungeness crabs released between Patrick's Point and the Klamath River, 1958.

TABLE 2. Number of Legal (159 mm) and Sublegal Sized Dungeness Crabs Released and Recovered Inside and Outside of Humboldt Bay, 1964–1967.

Tagging dates	*Inside Bay*						*Outside Bay*					
	Number released		*Number recovered*				*Number released*		*Number recovered*			
			Inside		*Outside*				*Inside*		*Outside*	
	sublegal	*legal*	*sublegal*	*legal*	*sublegal*	*legal*	*sublegal*	*legal*	*sublegal*	*legal*	*sublegal*	*legal*
Oct. 1964 to June 1965	383	64	1	3	3	3	487	88	0	0	84	53
July 1965 to Feb. 1966	84	1	0	0	1	0	263	0	0	0	28	0
July 1966 to June 1967	310	75	0	0	3	0	717	7	0	0	95	2
July 1967 to Nov. 1967	29	0	0	0	1	0	16	0	0	0	1	0
TOTAL	806	140	1	3	8	3	1,483	95	0	0	208	55

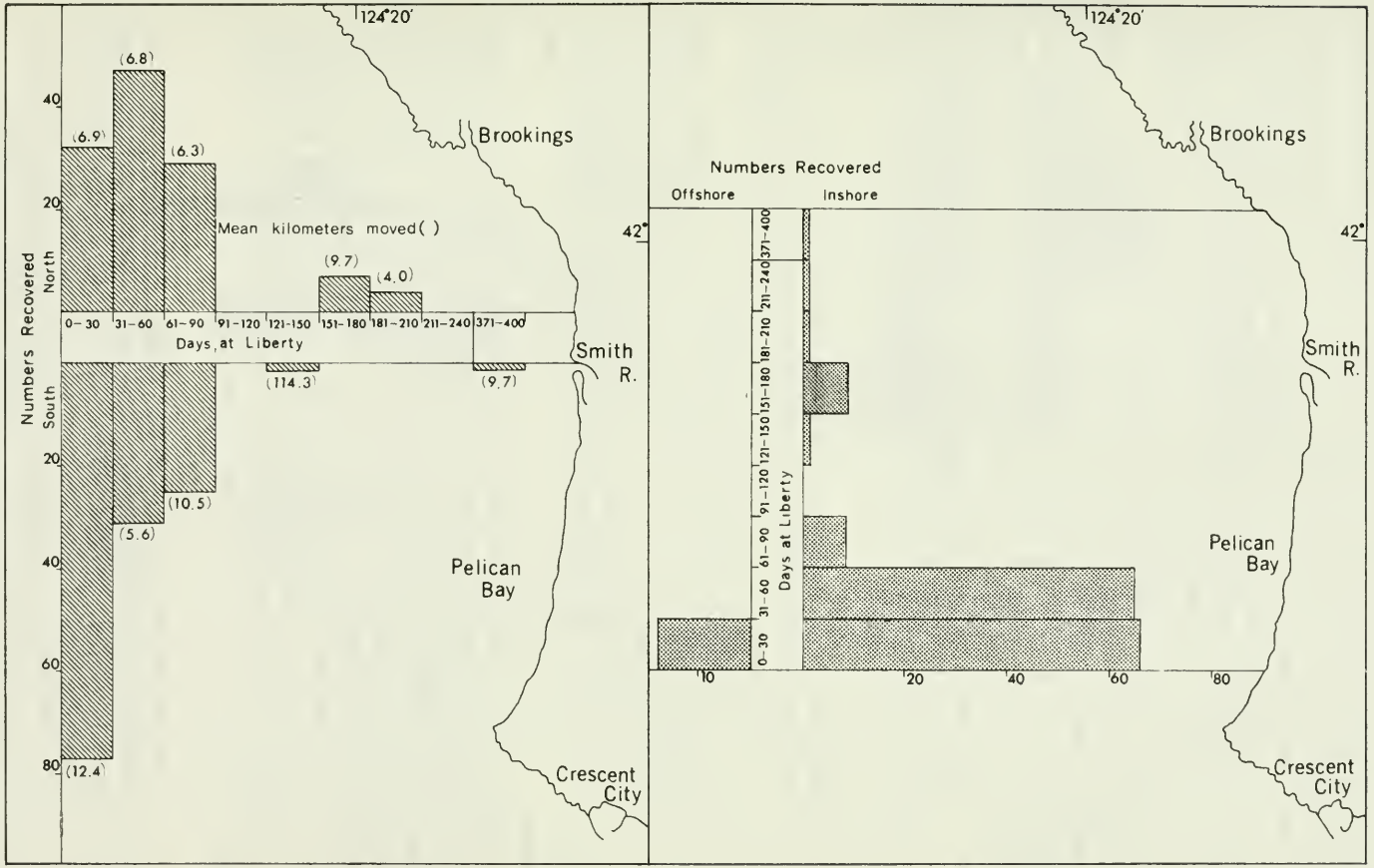

FIGURE 7. Recovery data for tagged Dungeness crabs released in Pelican Bay, 1962.

molted; most were released again by the fishermen. All crabs recovered during the 1965–66 season, however, had molted.

Two sublegal crabs released inside the Bay during November and December were recovered outside the Bay. One was recovered after 46 days at liberty 11 km (7 miles) north of the entrance to Humboldt Bay; and one was recovered after 473 days at liberty (during the 1965–66 fishing season) 8 km (5 miles) south of the entrance to Humboldt Bay. Only one of the legal sized males released during this period was recovered; after 32 days at liberty this crab had moved about 1.6 km (1 mile) southwest of the entrance to Humboldt Bay.

Eighteen (6%) of the sublegal sized crabs released outside of Humboldt Bay during November and December were recovered during the 1964–65 fishing season. Eleven (61%) of these moved north an average distance of 58.7 km (36.5 miles) (Figure 8). The average southerly movement for seven crabs was 15 km (9.3 miles). Eight crabs moved offshore from 4 to 39 m (2 to 21 fm); however, there were no offshore recoveries after 150 days of liberty. Nineteen crabs were recovered inshore of their release depths. The depth change ranged from 2 to 32 m (1 to 18 fm). One legal sized crab released outside the Bay during this period was recovered 6 km (4 miles) north of the release site after 180 days at liberty.

Five sublegal crabs were recovered during the 1965–66 fishing season; three north of the release site, one south, and one offshore with no corresponding north or south movement. One crab moved offshore and one inshore, and three were returned with insufficient depth of recovery data.

During January, February, and March, we tagged and released 182 sublegal and 33 legal sized males inside Humboldt Bay. Four (12%) of the legal sized crabs were recovered during the 1964–65 fishing season, all had moved outside the bay. Three moved south of the bay entrance an average of 12.9 km (8 miles), while one moved 3 km (2 miles) north. One of the sublegals was recovered outside the Bay during the 1964–65 season, 3 km (2 miles) north of the Bay entrance.

A total of 189 sublegal and 84 legal sized males was tagged and released outside of the bay during the same period. Commercial fishermen recovered 38 (20%) of the sublegals and 48 (57%) of the legals during the 1964–65 season (Figure 9). Forty-three (90%) of these legal sized crabs and 25 (66%) of the sublegals were recovered south of the release sites. Most of the 20 crabs recovered north of the release sites were from the March releases. The average southerly movement was 11.1 km (6.9 miles), the average northerly movement was 7.6 km (4.7 miles). Seven crabs moved offshore from 4 to 9 m (2 to 5 fm), the remaining 79 were recovered inshore of the release depth. Inshore movement ranged from 2 to 9 m (1 to 5 fm) (Figure 10).

1965

We continued the studies begun in 1964 by tagging an additional 348 crabs; 85 inside Humboldt Bay and 263 outside, all during November and December (Table 2, Figure 1). All but one were sublegal sized and, for the most part, those recovered during the 1965–66 season were released by the fishermen. Only one crab released inside the bay was recovered, having been captured 29 km (18 miles) south of the entrance to the bay after being at liberty 39 days.

Nine recoveries of crabs released outside the bay were made during the

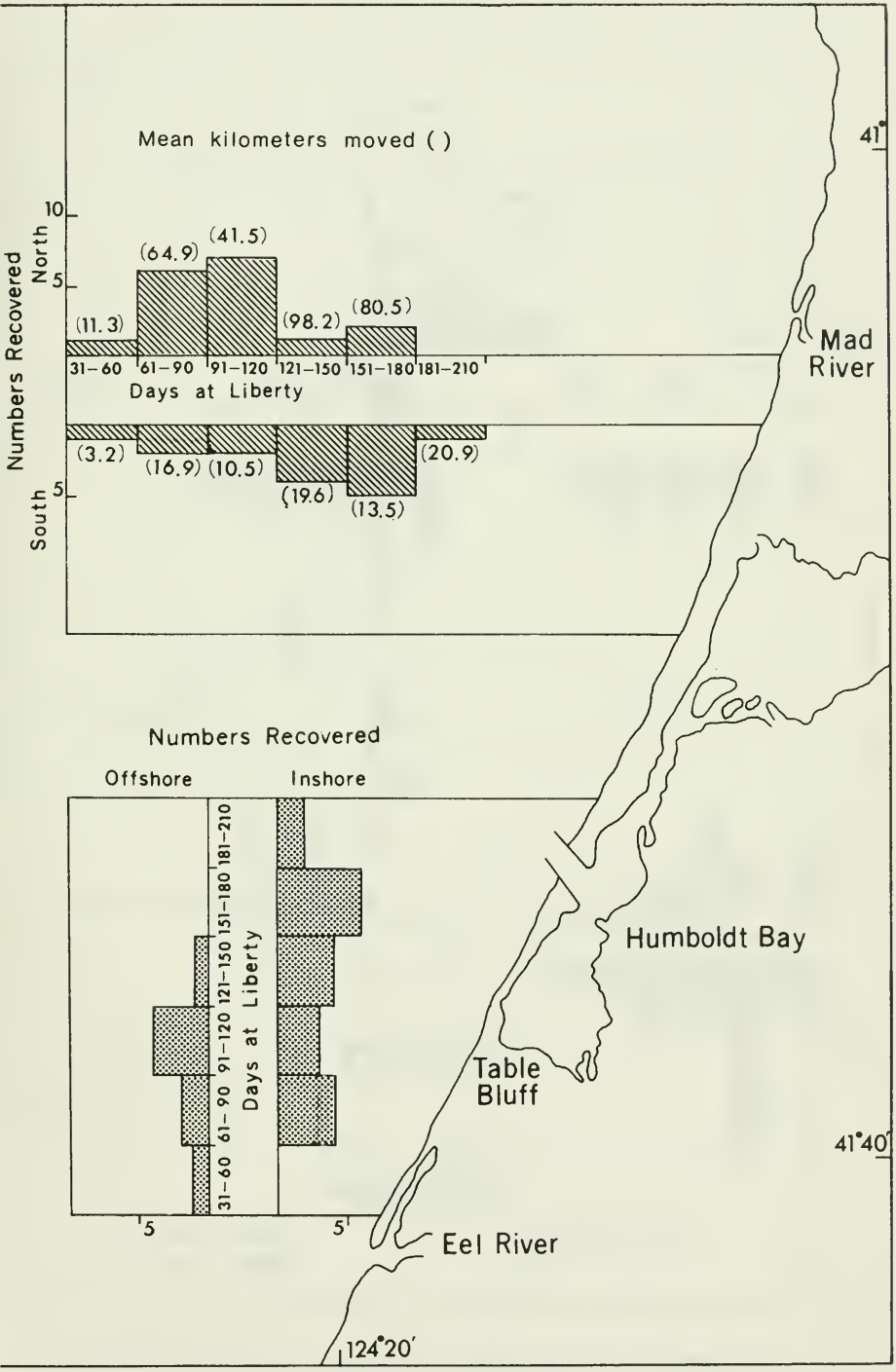

FIGURE 8. Recovery data for tagged Dungeness crabs released between the Eel River and Mad River, 1964.

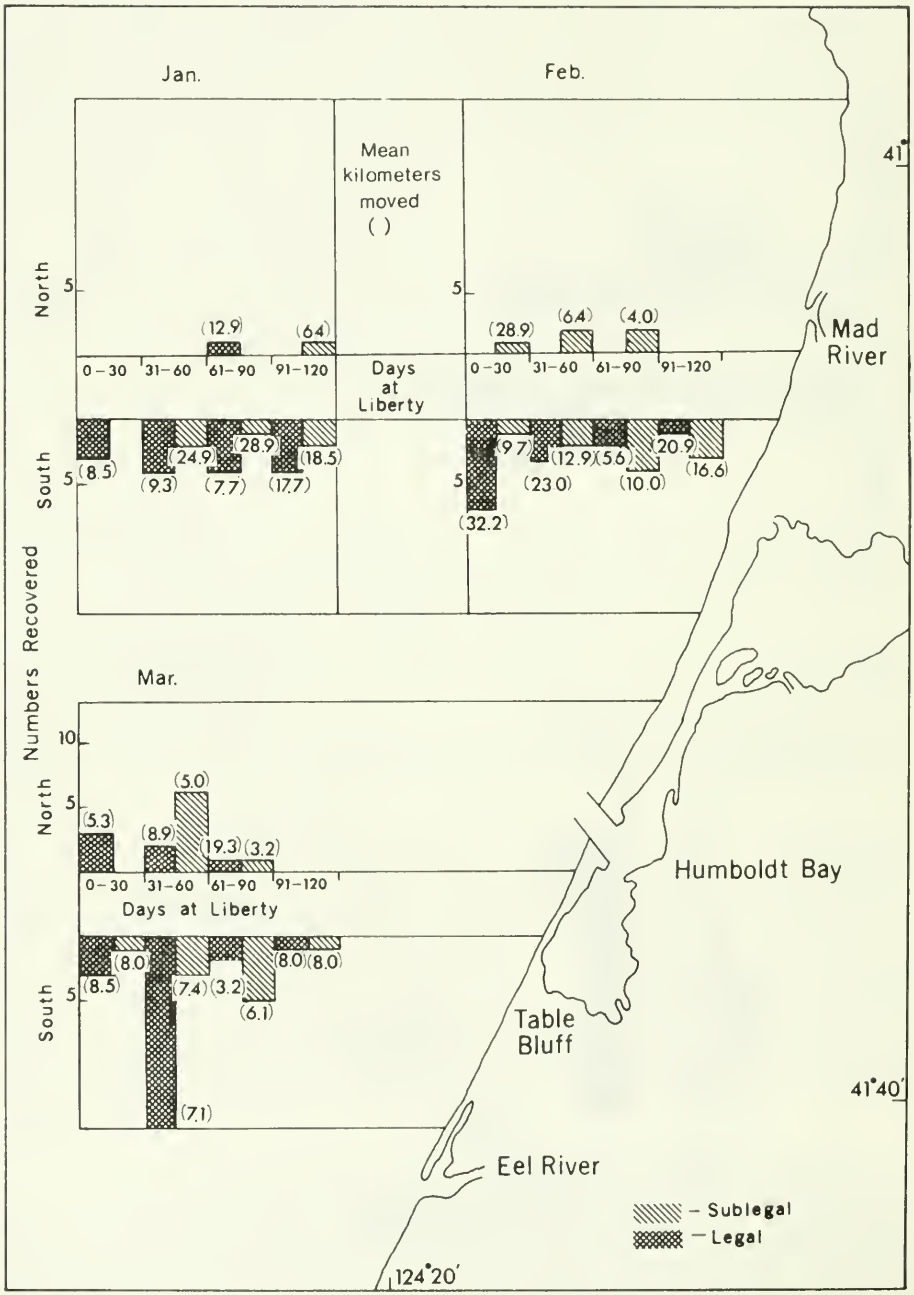

FIGURE 9. North-south recovery data for tagged Dungeness crabs released between the Eel River and Mad River, January to March, 1965.

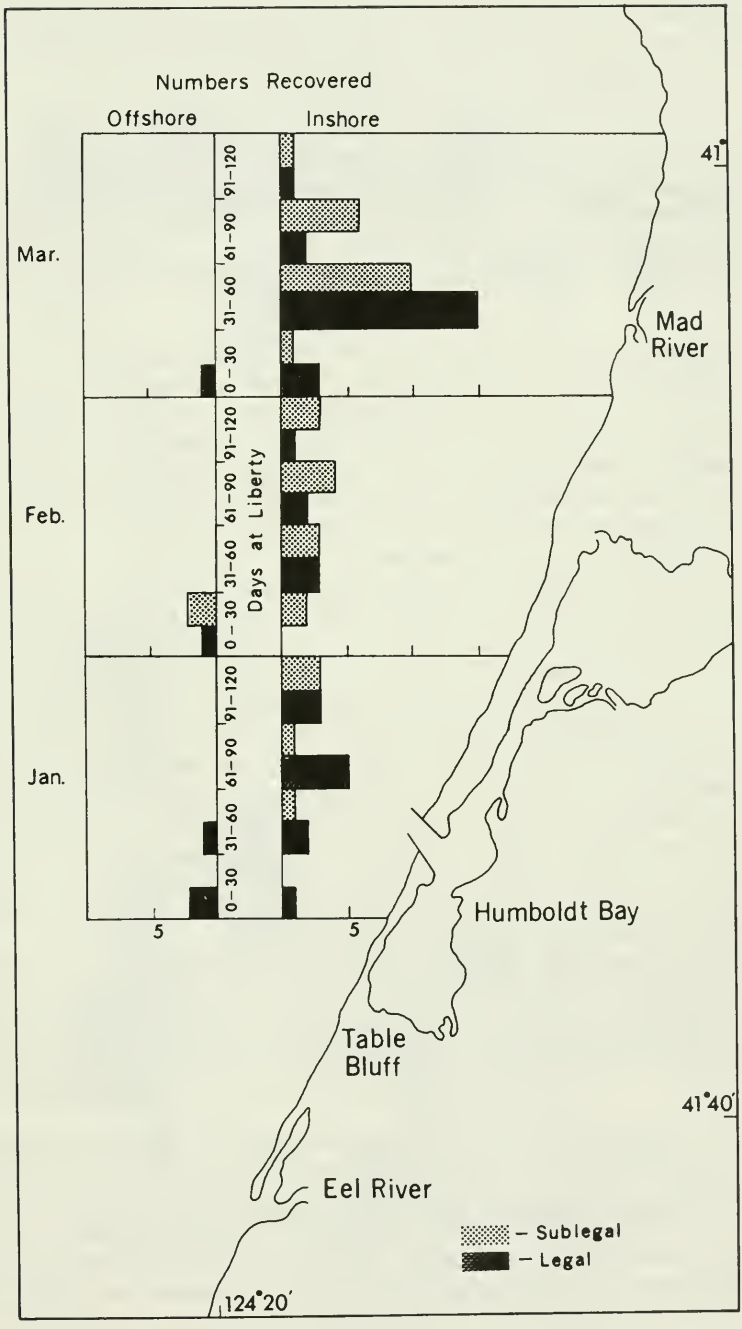

FIGURE 10. Inshore-offshore recovery data for tagged Dungeness crabs released between the Eel River and Mad River, January to March, 1965.

1965–66 season, five north and four south from the release site. Five crabs moved inshore, and two offshore from the release depth. The average northerly movement was 52.1 km (32.4 miles), the average southerly movement was 20.3 km (12.6 miles). Inshore movements ranged from 15 to 38 m (8 to 21 fm). Two tags were reported with incomplete depth of recovery data.

During the 1966–67 fishing season, 15 of these crabs released outside the Bay were recovered, all had molted. Four crabs were recovered south of the release site. They had moved an average of 18.5 km (11.5 miles). The 11 crabs recovered north of the release site moved an average of 60.8 km (37.8 miles). Most (10) had moved inshore of the release site 4 to 31 m (2 to 17 fm). The depth of recovery could not be determined for three crabs.

1966

To complete the movement studies, we released an additional 1,109 crabs between July 1966 and June 1967 (Table 2). Most of the crabs were released in water 6 to 15 m (3 to 8 fm), somewhat shallower than earlier studies which were released in 14 to 55 m (8 to 30 fm). Inside Humboldt Bay, we captured and tagged 310 sublegal and 75 legal sized crabs. Three of the sublegal sized crabs were recaptured during the 1966–67 fishing season, all outside of the Bay. Two of the crabs were recovered south of the Bay entrance and one north. None of the legal sized crabs was recaptured.

We captured and tagged 717 sublegal and 7 legal sized crabs between Humboldt Bay and Crescent City Harbor during November and December 1966. These crabs were released at the entrance to Humboldt Bay, in Trinidad Harbor, and in Crescent City Harbor. Of 229 crabs released off Humboldt Bay and in Trinidad Harbor, commercial fishermen reported capturing 47 sublegal and 2 legal sized crabs during the 1966–67 season. The fishermen released most of the undersized crabs. Thirty-one (64%) of the crabs were recovered north of their release sites (Figure 11); however, after 120 days at liberty, slightly over 50% (19) of the recoveries came from south of the release sites. The average northward movement was 23.5 km (14.6 miles). The average southerly movement was 13.2 km (8.2 miles). The majority had moved offshore, 3 to 36 m (2 to 20 fm), in direct contrast to previous experiments. All recoveries from shallower than release depths occurred after 90 days at liberty.

A total of 20 crabs was recovered during the 1967–68 season, 15 (75%) of the recoveries were from north of the release site, an average of 52.3 km (32.5 miles) (Figure 14). The average southerly movement was 19.6 km (12.2 miles). Of the crabs originally released in shallow water (4 to 8 fm), all but one moved to deeper water. The offshore change in depth ranged from 2 to 36 m (1 to 19.5 fm).

All of the recoveries from the 240 crabs (4 legals, 236 sublegals) released in Crescent City Harbor were made during the 1966–67 fishing season. Only 12 (5%) of these crabs were recovered. Eight crabs moved south an average of 23.8 km (14.8 miles) and three crabs moved an average of 26.2 km (16.3 miles) north of the harbor. One crab was recovered in the harbor. All recoveries with depth of capture data were from deeper water than the release depth, ranging from 3 to 43 m (2 to 24 fm).

1967

A few sublegal sized crabs were tagged and released in Humboldt Bay during

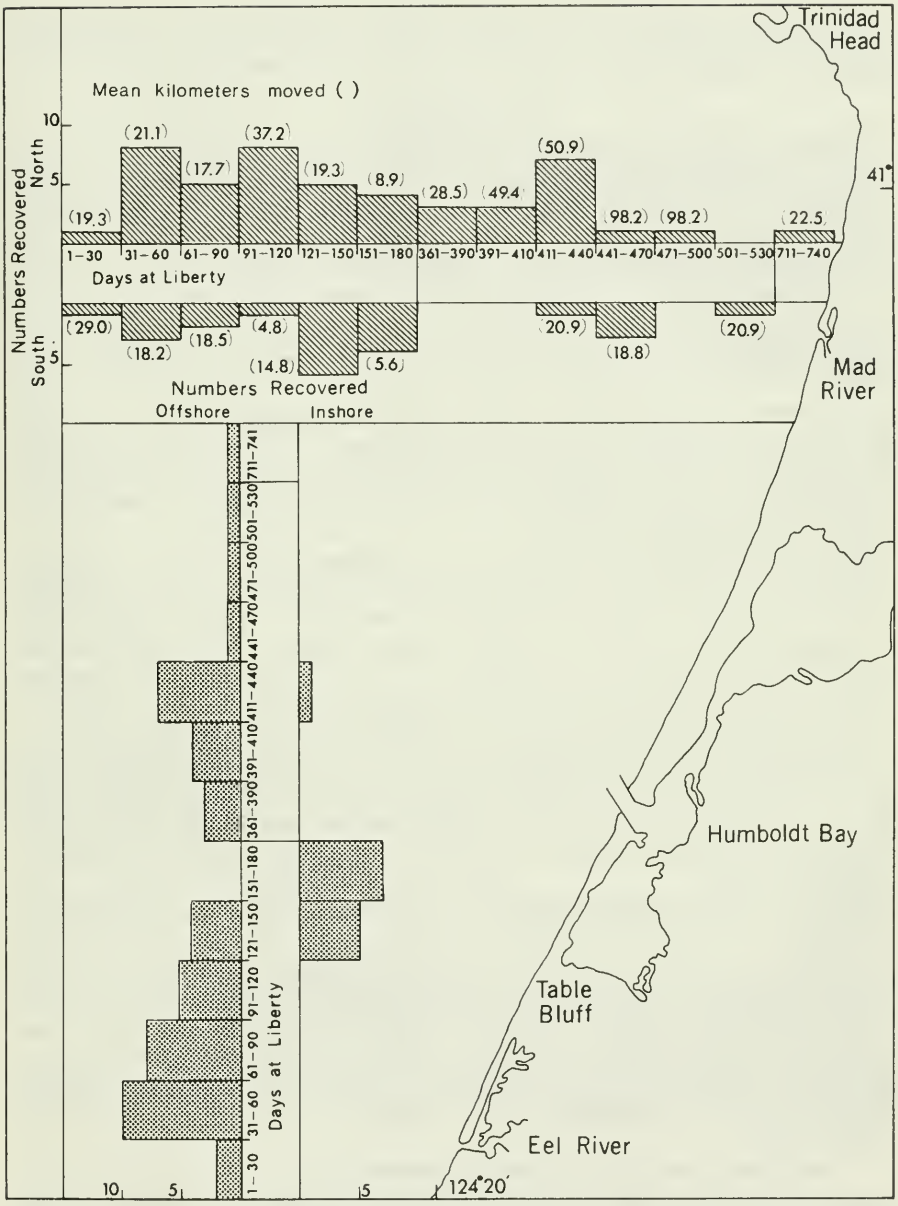

FIGURE 11. Recovery data for tagged Dungeness crabs released between Humboldt Bay and Trinidad, 1966.

1967 (Table 2): 220 from January through June and 29 from July through October. Three of these crabs were recovered outside of the Bay, one moved 6 km (4 miles) north and two an average of 11.3 km (7 miles) south of the entrance to the Bay. All were recovered deeper than the original release depth.

One crab recovered 60 km (36 miles) north of the entrance came from a group of 16 released at the entrance to the Bay in November.

DISCUSSION

Obviously, tag recovery locations depend upon where the fishermen fish their traps. In northern California commercial fishermen begin the season fishing in depths from 18 to 73 m (10 to 40 fm). During the 1969–70 season, some fishermen were fishing as deep as 183 m (100 fm). As the catch-per-unit-of-effort decreases in deeper waters, the traps are set in shallower water. By April most traps are inside 18 m (10 fm). During the past 10 to 15 years, traps have been fished in most of the crab producing areas between Fort Bragg and the California-Oregon border, particularly during the first 3 or 4 months of the season. After the end of March, a large share of the fishermen leave the crab fishery, hence, the area covered by the traps decreases significantly from April until the end of the season in July. The results of all the studies have been influenced by the aforementioned fishing patterns, thus the movement patterns about to be discussed are influenced to a similar degree by the seasonal characteristics of the commercial fishery.

Most of the crabs tagged during these studies were legal-sized males. Because there does not appear to be a significant difference in the movement patterns of the smaller males (based on the results of the 1964–65 study), recovery data from legal as well as under-sized crabs are lumped together. Some of the studies produced very small numbers of returns. Thus, most emphasis was placed on those particular studies that yielded the highest return rates.

At first glance, the movements of crabs recorded during any one of the studies do not present a definite pattern with the exception of the inshore-offshore shifts. Jow (1960, 1965) felt that the returns from the crabs released in Pelican Bay in 1962, as well as data from the 1958 study, indicated intermingling of northern California and southern Oregon populations. He also pointed out the inshore movements trend.

I believe that examination of recovery data from all the studies suggests the following:

1. Northern California male crabs, with the exception of crabs found in the Usal-Shelter Cove area, tend to move offshore during the months of November through March, then return to shallow water from March through June.

2. Crabs tagged in the area from Usal to Shelter Cove remained in that area, making only short movements north or south. None of these tagged crabs was recovered north of Cape Mendocino, and only two crabs were recovered south of Fort Bragg.

3. Crabs from False Cape to Trinidad, and to a certain extent, to the Klamath River, tend to move north from November through March. In all seven of the studies conducted between the Eel River and the Klamath River, the majority of tagged crabs released in November and December moved north, with one exception; crabs released between Patrick's Point and the Klamath River in November and December 1958, showed an equal tendency to move north or south.

4. Crabs released between the Klamath River and Crescent City tended to move south from November through March.

5. Pelican Bay crabs tended to move south during the first part of the fishing season.

6. A substantial number of crabs from all of the studies remained in the same area for long periods.

7. Crabs probably move with prevailing currents, particularly north and south shifts. The north flowing Davidson current usually takes precedence off northern California in November or December (Sverdrup, Johnson, and Fleming 1954). The Davidson current disappears in late winter (February to April) with the onset of prevailing northerly winds. Southerly movements observed during Davidson current periods might be due to local eddy currents, particularly in Pelican Bay and between the Klamath River and St. George Reef.

8. Benthic juvenile and adult crabs in the area between Fort Bragg and Cape Mendocino are a discrete population with no immigration and very little emigration.

9. For all practical purposes, crabs from Cape Mendocino to Pelican Bay should be considered one population, although there is more evidence of immigration and emigration. Only 43 crabs released in this area were recovered north of the Oregon-California border. None of the crabs released north of Cape Mendocino has been recovered south of the Cape. Oregon biologists (Darrell Demory, Oregon Fish Commission, pers. commun.) report that out of 113 crabs tagged off Port Orford and returned with catch data, only one was recovered south of Brookings.

10. There is little or no movement of adult crabs into Humboldt Bay, particularly legal sized adults.

Cleaver (1949) found that tagged Dungeness crabs off Washington moved north during late winter and had some evidence of return movement. He speculated that the crabs moved to deeper water and moved south during the summer. Crabs living between Cape Mendocino and the Klamath River seem to follow this pattern.

I propose the following models for northern California male crab migration: From Cape Mendocino to the Klamath River, most males are in shallow water in the late spring and early summer; as summer progresses, the crabs move offshore and south with the prevailing currents. This movement continues at least until December or January, then the crabs move toward shore and northward with the Davidson current. The speculation regarding movements during the summer and fall when the season is closed are based on crabs recovered during their second season at liberty. From the Klamath River to Brookings, Oregon, male crabs move to the north and offshore in late summer through early winter; during late winter and spring, crabs move inshore and to the south.

ACKNOWLEDGMENTS

The following are thanked for their participation in the 1964–67 tagging studies: Nancy Nelson, Mel Willis, Steve Taylor, Bob Hardy, Pete Brown, and the Captain and crew of the *N.B. Scofield*. Cathy Short produced the figures for all of the studies. Tom Jow and Walt Dahlstrom provided many helpful comments and background information on the 1956 to 1962 experiments. Their assistance and contributions are gratefully acknowledged. Finally, I would like to thank all of the commercial fishermen who cooperated in the experiments by returning tags and catch data.

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Calif. Fish and Game 64(4): 255–267 1978

FOOD SELECTION BY FIVE SYMPATRIC CALIFORNIA BLACKBIRD SPECIES [1]

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The percent volume of food items in stomachs and esophagi was tabulated for 875 adult and subadult blackbirds of five species (tricolored blackbird, *Agelaius tricolor;* red-winged blackbird, *A. phoeniceus;* yellow-headed blackbird, *Xanthocephalus xanthocephalus;* brown-headed cowbird, *Molothrus ater;* and Brewer's blackbird, *Euphagus cyanocephalus*) collected in the Sacramento Valley, California, 1967–72. Seeds of cultivated grains, chiefly rice (*Oryza sativa*), made up 24% to 54% of the annual diet of all species. Rice was eaten more than any other food by red-winged (43.7%), yellow-headed (38.0%), and tricolored blackbirds (37.8%). Water grass (*Echinochloa* spp) was the primary food of brown-headed cowbirds (45.9%), and wild oats (*Avena* spp) the primary food of Brewer's blackbirds (17.6%). Insects were eaten most in the spring and summer and made up 3 to 24% of the annual diet.

Statistical comparisons of percent volume for 11 major food classes (treating stomachs and esophagi separately) revealed many significant ($p \leq .05$) differences in food selection among species. Similar comparisons for six food classes also showed some significant differences among tricolor and red-wing sex and age classes. The differences among species and between sexes are likely related to differences in bill size and structure, which affect the size of seeds that can be handled efficiently and the ease of catching insects. The differences between adults and subadults are likely related to difference in feeding experience. The use of rice by red-wings and Brewer's has increased greatly since 1900 and 1931, mainly because of changes in crop acreages and continued conversion of marshes and fields to agricultural uses.

INTRODUCTION

Many agricultural damage problems by blackbirds involve several different species that often feed together in mixed flocks. Biologists generally recognize that not all blackbird species, or even all sex and age classes within a species, contribute equally to damage, but no detailed analysis has been made of the relative importance of these various groups for specific damage situations.

From 1964 through 1974, personnel of the U.S. Fish and Wildlife Service studied blackbird damage to rice in the Sacramento Valley of California. The problem is complex because five species (eight subspecies) of blackbirds are present, as resident and migrant populations, during the fall damage season: the tricolored blackbird, red-winged blackbird (*A. p. californicus, A. p. caurinus,* and *A. p. nevadensis*), yellow-headed blackbird, brown-headed cowbird (*M. a. artemisiae* and *M. a. obscurus*), and Brewer's blackbird.

Very little has been published on the foods of tricolored blackbirds, brown-headed cowbirds, and yellow-headed blackbirds in California, and food habits studies of red-winged and Brewer's blackbirds in California by Beal (1900), Bryant (1912), Soriano (1931), and others were done before the era of intensive rice culture. Studies were started in the fall of 1967 to determine the food of each blackbird species during the fall damage season and were later expanded to

[1] Accepted for publication June 1978.
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include all seasons. This paper summarizes the seasonal and annual foods of adults and flying young of all five species and examines differences in food selection among species and between tricolor and redwing sex and age classes. Data we gathered on the food of nestling tricolors have been reported elsewhere (Crase and DeHaven 1977).

STUDY AREA

Blackbirds were collected in Colusa, Glenn, and Butte counties, the major rice-growing areas of the Sacramento Valley. This area is intensively farmed. Rice is the primary crop, but grain sorghum (*Sorghum vulgare*), safflower (*Carthamus tinctorius*), barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), and fruit and nut crops are also grown. Four wildlife refuges provide areas of natural marsh for nesting and roosting and also contain fields of rice and water grass grown to reduce waterfowl damage on nearby non-refuge lands. Several private gun clubs maintain areas of natural marsh. The Sacramento River, numerous irrigation canels, drainage ditches, and sinks provide additional semi-natural marsh habitat for blackbirds.

METHODS

About 80% of the 875 birds used for this study were shot at random from evening flightlines into major communal roosts or in adjacent staging areas. The remaining 20% were shot in loafing and breeding areas during spring when the birds do not congregate into large roosts. Birds were taken on 74 different days from September 1967 through June 1972 (averaging 11.8 birds/day) and during all months of the year. Each sample was frozen as soon as possible, usually within 2 hours of collection. For examination, each bird was thawed and dissected, and the contents of each esophagus and stomach (gizzard and proventriculus) were washed, assigned a number, air dried on blotter paper, and examined under low magnification. Food items were identified and segregated into piles, and the precentage of the total volume of each item was visually estimated.

To examine food selection differences statistically, annual volume percentages for major food groups were compared among species and between sex and age classes for tricolors and red-wings. Comparisons were made by single-classification analyses of variance on arcsin-transformed data, and the means separated by Duncan's new multiple-range test; $p \leq 0.05$ was accepted as significant. For the among species comparison, each species was compared separately with every other species (10 species pairs) for each food item; the esophagi and stomachs were treated separately to remove digestion rates and percentage of empty esophagi as variables in the comparison. Eleven food classes were compared for stomach contents, and 10 for esophageal contents (esophageal grit could not be meaningfully compared); thus, 21 tests for food selection differences were made for each species pair. For the comparisons between sex and between age for tricolors and red-wings, the same tests were made for six food classes except that esophageal and stomach data were combined.

RESULTS

Plant Foods

Rice was an important food for all five blackbird species. In terms of volume, it ranked first in the annual diet of red-wings, yellow-heads, and tricolors, second

in the diet of cowbirds, and third in the diet of Brewer's (Table 1). Generally, rice consumption was highest during the fall when maturing fields provided a super-abundant food source, but large amounts also were eaten during the winter when it was available as waste in harvested fields.

Water grass seed was the next most important blackbird food. It was eaten more than any other item by brown-headed cowbirds and was second in importance for red-wings, tricolors, yellow-heads, and Brewer's. Although the volume of water grass eaten was usually less than that of rice, the number of seeds taken was greater because rice seeds are four to five times larger than water grass seeds.

Seeds of cultivated grains (including rice) made up about one-half of the total annual food volume of red-wings, yellow-heads, and tricolors, one-third of the food of cowbirds, and less than one-fourth of the food of Brewer's blackbirds. Of these grains, sorghum was second in volume after rice and was eaten in similar percentages by all five species. Safflower, wheat, and cultivated oats were also eaten, but in relatively small amounts. The esophagi contained higher percentages of cultivated grains than did the stomachs. This may reflect some differential digestion (see Discussion), but, because most of our collections were from incoming flightlines to roosts, it may also be the result of the birds "filling up" on readily available food just before roosting.

Wild oats, a common weed along roads and ditches and in fallow fields, ranked first in the annual diet of Brewer's blackbirds. Oats were over 5% of the diet of tricolors but were found in only small amounts, or were absent, in red-wings, yellow-heads, and cowbirds.

Other wild seeds were eaten in small amounts by all species. Smartweed (*Polygonum* spp), pigweed (*Amaranthus* spp), filaree (*Erodium* spp), and Johnson grass (*Sorghum halepense)* were the most common, but Bermuda grass (*Cynodon dactylon)*, switch grass (*Panicum* spp), catchfly (*Silene* spp), bulrush (*Scirpus* spp), canary grass (*Phalaris* spp), and sprangletop (*Lepthochloa* spp) were also eaten.

Animal Foods

Insects made up most of the animal food of all species. Beetles (Coleoptera) were the main insect food of Brewer's, tricolors, and red-wings, whereas miscellaneous adult insects ranked highest for cowbirds and yellow-heads. Ground-dwelling beetles (Carabidae, Tenebrionidae, and Chrysomelidae) and water beetle larvae (Hydrophilidae) were the most important insect food of tricolors and red-wings, and ground-dwelling beetles and weevils (Curculionidae) were the insects eaten in the largest volumes by Brewer's. These beetle groups were also the primary food of tricolor nestlings from the same general area (Crase and DeHaven 1977). Brewer's blackbirds ate a much larger volume of grasshoppers and crickets (Orthoptera) than did the other four species. Generally, insects were eaten most abundantly during the spring and early summer, the blackbird breeding season. Hintz and Dyer (1970) have suggested that increased insect consumption by adult red-wings during the breeding season was related to both the increased availability of insects and the limited foraging time available to obtain their required energy (due to the demands of breeding activity).

TABLE 1. Percent Volume of Foods Found in the Esophagi and Stomachs of Five California Blackbird Species in Winter (Dec-Feb), Spring (Mar-May), Summer (Jun-Aug), and Fall (Sep-Nov). (Sample sizes are given in parenthesis.)

	Tricolored blackbird					*Red-winged blackbird*					*Brown-headed cowbird*				
Food Item	*Win. (37)*	*Spr. (35)*	*Sum. (90)*	*Fall (105)*	*Annu. (267)*	*Win. (100)*	*Spr. (99)*	*Sum. (16)*	*Fall (168)*	*Annu. (384)*	*Win. (29)*	*Spr. (38)*	*Sum. (43)*	*Fall (20)*	*Annu. (130)*
Rice	37.4	47.9	16.8	49.1	37.8	48.4	25.7	36.1	64.5	43.7	49.3	28.4	3.4	21.6	25.7
Sorghum	8.4	0.9	11.9	9.0	7.6	18.3	1.2	12.0	3.3	8.7	8.6	0.7	18.7	2.1	7.5
Safflower	0.0	0.0	1.6	2.3	1.0	0.0	4.0	0.0	1.8	1.4	0.0	0.0	0.0	0.6	0.2
Wheat	7.2	0.0	0.4	0.0	1.9	0.0	1.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Other grain	0.0	0.0	0.0	2.4	0.6	0.0	0.0	0.0	T	T	0.0	0.0	0.0	0.0	0.0
Oats	10.6	0.0	9.1	1.7	5.4	0.9	6.4	0.0	T	1.8	0.2	0.2	0.0	0.8	0.3
Water grass	22.1	13.4	12.2	21.7	17.4	16.9	26.5	37.3	18.7	24.8	33.2	23.5	62.0	65.0	45.9
Smartweed	1.0	0.4	0.8	2.4	1.2	1.5	1.1	0.6	3.2	1.6	1.6	0.7	5.6	1.0	2.2
Pigweed	0.0	T	0.0	0.5	0.2	0.0	T	0.0	0.0	T	0.0	0.0	0.0	0.0	0.0
Johnson grass	0.0	0.0	2.3	0.6	0.7	0.1	0.1	0.0	0.2	0.1	0.4	0.0	0.4	0.0	0.2
Other wild seeds	1.7	2.6	1.1	1.4	1.7	0.6	6.2	0.6	1.9	2.3	2.2	26.7	1.5	1.8	8.0
Misc. plant	0.0	T	T	T	T	0.0	0.0	0.0	T	T	0.0	0.1	0.0	0.0	T
Total cultivated grain	53.0	48.8	30.3	62.7	48.7	66.7	32.1	48.1	69.6	54.1	57.8	29.2	22.1	24.3	33 4
Total wild seed	35.4	16.5	25.6	28.4	26.5	20.1	40.4	38.5	24.1	30.1	37.7	51.1	69.5	68.6	56.7
Total plant	88.4	65.3	55.9	91.1	75.2	86.8	72.5	86.6	93.7	84.9	95.5	80.3	91.6	92.9	90.1
Coleoptera															
Ground beetles	2.4	9.7	6.1	1.8	5.0	1.7	6.1	1.1	0.4	2.3	0.4	1.8	0.6	0.4	0.8
Weevils	0.5	2.5	0.3	0.2	0.9	0.2	2.4	0.0	0.1	0.7	0.0	0.3	0.0	0.0	T
Water beetles															
Adults	0.2	0.4	0.2	0.0	0.2	0.0	0.4	0.0	0.0	0.1	0.0	0.4	0.0	0.1	0.1
Larvae	0.0	6.5	18.6	0.1	6.3	0.0	1.3	5.8	0.0	1.8	0.0	0.2	0.0	0.0	T
Orthoptera	0.0	1.9	5.6	0.5	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	T
Diptera	0.3	0.3	0.2	0.2	0.2	0.6	1.1	0.0	0.3	0.5	T	0.4	0.0	0.0	0.1
Hemiptera	0.0	0.2	0.6	0.2	0.2	0.1	T	0.6	0.2	0.2	0.0	0.0	0.0	0.4	0.1
Misc. insects															
Adults	0.2	0.8	3.0	3.3	1.8	0.4	0.8	1.4	3.0	1.4	T	0.8	1.8	3.0	1.4
Larvae	0.2	1.6	3.4	0.5	1.4	0.2	4.7	1.6	0.1	1.6	0.0	0.9	0.0	0.1	0.2
Arachnida	0.0	2.1	1.0	0.3	0.8	0.5	0.1	0.7	0.3	0.4	0.1	0.0	0.0	0.1	T

TABLE 1—*Continued*

Mollusca	0.0	0.2	0.2	0.2	0.2	0.0	T	0.0	0.1	T	0.0	0.2	0.0	0.3	0.1
Misc. animal	0.4	1.7	T	T	0.6	0.6	0.2	0.0	T	0.2	0.0	0.0	0.0	0.0	0.0
Total beetles	3.0	19.1	25.3	2.1	12.4	1.9	10.2	6.9	0.5	4.9	0.4	2.7	0.6	0.6	1.1
Total insects	3.8	23.9	38.1	6.9	18.2	3.2	16.9	10.5	4.0	8.6	0.5	4.9	2.6	4.1	3.0
Total animal	4.2	27.9	39.3	7.5	19.7	4.4	17.3	11.1	4.4	9.3	0.6	5.2	2.6	4.5	3.2
Grit	7.4	6.6	4.5	1.4	5.0	8.8	10.2	2.4	2.1	5.9	4.1	14.5	5.7	1.8	6.5

	Yellow-headed blackbird					*Brewer's blackbird*				
Food item	*Win. (0)*	*Spr. (12)*	*Sum. (2)*	*Fall (10)*	*Annu. (24)*	*Win. (23)*	*Spr. (19)*	*Sum. (4)*	*Fall (24)*	*Annu. (70)*
Rice	—	80.6	0.0	35.5	38.0	20.0	11.9	0.0	26.2	14.5
Sorghum	—	0.0	3.0	31.3	11.4	26.0	0.5	0.0	2.8	7.3
Safflower	—	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.9	0.4
Wheat	—	0.0	0.0	0.0	0.0	0.0	3.3	0.0	3.1	1.6
Other grain	—	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oats	—	0.0	0.0	0.0	0.0	2.7	25.3	36.0	6.5	17.6
Water grass	—	7.8	76.3	16.4	33.5	15.1	15.9	8.8	27.5	16.8
Smartweed	—	0.1	0.0	4.2	1.4	0.2	0.0	0.0	0.9	0.3
Pigweed	—	0.0	0.0	0.0	0.0	0.0	0.0	0.0	T	T
Johnson grass	—	0.0	0.0	5.2	1.7	1.3	0.0	0.0	0.5	0.4
Other wild seeds	—	0.2	0.0	T	T	2.6	10.0	3.5	2.5	4.6
Misc. plant	—	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total cultivated grain	—	80.6	3.0	64.7	49.4	46.0	16.7	0.0	32.9	23.9
Total wild seed	—	8.0	76.3	25.8	36.7	21.9	51.3	48.3	38.0	39.9
Total plant	—	88.6	79.3	90.5	86.1	67.9	68.0	48.3	70.9	63.8
Coleoptera										
Ground beetles	—	0.3	0.3	0.0	0.2	6.0	14.7	13.8	8.0	10.6
Weevils	—	0.0	0.0	0.2	T	0.0	2.8	5.0	1.1	2.2
Water beetles										
Adults	—	0.4	0.0	0.0	0.1	0.0	0.2	0.0	0.0	T
Larvae	—	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.3
Orthoptera	—	0.0	0.0	0.0	0.0	0.0	0.0	23.8	2.6	6.6

TABLE 1.—*Continued*

Food item	*Yellow-headed blackbird*					*Brewer's blackbird*				
	Win. (0)	*Spr. (12)*	*Sum. (2)*	*Fall (10)*	*Annu. (24)*	*Win. (23)*	*Spr. (19)*	*Sum. (4)*	*Fall (24)*	*Annu. (70)*
Diptera	—	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.5
Hemiptera	—	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.6
Misc. insects										
Adults	—	0.0	20.0	6.9	9.0	T	0.3	0.0	10.6	2.8
Larvae	—	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arachnida	—	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mollusca	—	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.2	0.2
Misc. animal	—	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.3
Total beetles	—	0.6	0.3	0.2	0.4	6.0	18.9	18.8	9.0	13.2
Total insects	—	0.6	20.3	7.2	9.4	6.1	21.5	42.6	24.5	23.7
Total animal	—	0.6	20.3	7.2	9.4	7.8	21.5	42.6	24.6	24.1
Grit	—	10.2	0.0	2.0	4.1	23.9	10.7	9.2	3.7	11.9

Grit

Mineral grit was about 5% of the total food volume for all species except Brewer's, for which it was about 12%. The figure for Brewer's is probably an overestimate of actual intake because 89% of the esophagi for this species were empty (see Discussion). Grit intake for all species was generally highest during the spring and lowest during the fall. This contrasts with the findings of Bird and Smith (1964) and Mott et al. (1972), who found that the least amount of mineral grit was picked up when insects were a large portion of the diet.

Species Differences

In the examination of food selection differences among blackbird species, the number of significant differences between species pairs ranged from 1 (5%) to 19 (90%) (Figure 1). Only one food class, grain sorghum, did not show at least one significant difference among species (Table 2).

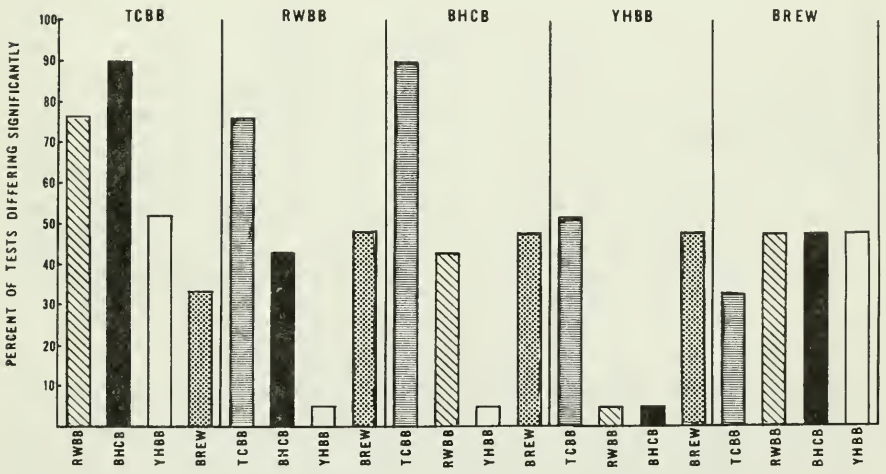

FIGURE 1. Differential consumption of 11 food classes, testing esophageal and stomach contents separately (21 tests), by five blackbird species in the Sacramento Valley, California; TCBB = tricolored blackbird, RWBB = red-winged blackbird, BHCB = brown-headed cowbird, YHBB = yellow-headed blackbird, BREW = Brewer's blackbird.

Considering some of the unavoidably small sample sizes for some of the comparisons, it appears that the Brewer's and tricolor are most alike in their food habits, and their food habits in turn differ most from that of the cowbird. The tricolor and red-wing showed a large difference in food selection considering their close phylogenetic relationship. The few statistical differences between yellow-heads and the other four species are probably partly due to the small sample size for this species. Likewise, the large number of empty Brewer's esophagi may have affected the number of significant differences between this and the other species. At any rate, each species apparently has its own pattern of utilizing the available food supply.

TABLE 2. Differences in Consumption of Major Food Items (percent of total annual volume in the esophagi and stomachs) Among Five California Blackbird Species.*

Food Item	*Tricolored blackbird*	*Red-winged blackbird*	*Brown-headed blackbird*	*Yellow-headed blackbird*	*Brewer's blackbird*
		Esophagus			
N =	(173)	(294)	(96)	(21)	(8)
Rice	43.0^{a}	55.2^{b}	30.5^{c}	47.7^{b}	22.8^{c}
Grain sorghum	9.6^{a}	8.8^{a}	9.2^{a}	14.4^{a}	16.5^{a}
Oats	5.0^{a}	2.1^{b}	0.3^{b}	0.0	5.8^{ab}
Water grass	12.4^{a}	19.8^{b}	43.2^{c}	34.7^{ab}	5.4^{ab}
Cultivated grains	57.1^{a}	66.5^{b}	40.0^{c}	62.1^{d}	39.3^{abc}
Wild seeds	19.9^{a}	24.8^{a}	55.7^{b}	36.7^{a}	13.1^{a}
Plant matter	77.0^{a}	91.3^{b}	95.7^{b}	98.8^{b}	52.4^{a}
Ground-dwelling beetles	3.0^{a}	1.1^{b}	0.4^{b}	0.0	2.5^{ab}
All beetles	13.6^{a}	1.8^{b}	0.5^{b}	0.3^{b}	6.9^{ab}
All insects	19.6^{a}	7.5^{b}	2.9^{b}	0.5^{b}	22.4^{a}
		Stomach			
N =	(267)	(384)	(130)	(21)	(70)
Rice	34.0^{x}	35.7^{y}	22.0^{z}	29.3^{xy}	13.6^{z}
Grain sorghum	6.3^{x}	8.3^{x}	6.4^{x}	8.8^{x}	6.1^{x}
Oats	5.6^{x}	1.6^{y}	0.3^{y}	0.0	17.8^{z}
Water grass	20.8^{x}	28.4^{x}	47.7^{y}	35.0^{x}	17.9^{x}
Cultivated grains	43.0^{x}	45.3^{y}	28.5^{z}	38.1^{xy}	22.5^{z}
Wild seeds	31.3^{x}	35.3^{xy}	57.7^{z}	39.3^{x}	41.6^{y}
Plant matter	74.3^{x}	80.6^{y}	86.2^{y}	$77.4^{x}y$	64.1^{x}
Ground-dwelling beetles	6.2^{x}	3.0^{y}	1.1^{y}	0.4^{y}	11.2^{z}
All beetles	11.9^{x}	6.7^{y}	1.5^{y}	0.5^{y}	13.5^{x}
All insects	17.6^{x}	9.4^{y}	3.0^{z}	14.5^{uz}	23.3^{x}
Grit	8.1^{x}	9.9^{x}	10.6^{x}	8.0^{xy}	13.0^{y}

* Means compared using arcsin-transformed data. Within each food item and organ, means followed by different superscript letters are significantly different ($p \leq 0.05$). Zero values cannot be compared by analysis of variance.

Sex Differences

For both tricolors and red-wings, six food classes were compared for differential selection by sex (Table 3). Both tricolor and red-wing males ate significantly more rice, cultivated grain, and plant matter than did females of the same species. The females of both species ate significantly more wild seed than did males. In addition, tricolor females ate significantly more insect matter than did tricolor males.

Age Differences

For tricolors and red-wings, differences in consumption of the same six food groups between age classes (adult vs. subadult) were less pronounced than differences among species and between sexes (Table 3). For both species, the two age classes ate almost identical percentages of rice and cultivated grain, but subadult tricolors ate significantly more wild seed and significantly less insect matter than did adults. For red-wings, there were no significant differences between adults and subadults in consumption of wild seed, plant matter, beetles, or insect matter.

TABLE 3. Sex and Age Differences in the Consumption of Selected Food Items (percent of total annual volume, esophagi and stomachs combined) by Tricolored and Red-winged Blackbirds.

Food item	Sex				Age			
	Tricolored blackbird		Red-winged blackbird		Tricolored blackbird		Red-winged blackbird	
	Male	Female	Male	Female	Adult	Subadult	Adult	Subadult
N =	(143)	(124)	(230)	(154)	(224)	(43)	(329)	(55)
Rice	47.6[a]	28.0[b]	49.5[x]	37.8[y]	38.1[a]	37.5[a]	43.8[x]	43.6[x]
Cultivated grain	58.4[a]	38.0[b]	62.0[x]	46.2[y]	48.4[a]	49.0[a]	54.3[x]	53.9[x]
Wild seeds	22.3[a]	30.7[b]	26.2[x]	35.4[y]	18.8[a]	34.2[b]	29.2[x]	32.4[x]
Plant matter	79.4[a]	71.0[b]	87.7[x]	82.1[y]	65.2[a]	85.2[b]	83.4[x]	86.2[x]
Beetles	10.8[a]	13.0[a]	4.1[x]	5.7[x]	20.0[a]	4.8[b]	5.4[x]	4.4[x]
All insects	15.6[a]	20.8[b]	7.6[x]	9.6[x]	27.7[a]	8.7[b]	8.7[x]	8.5[x]

* Means compared using arcsin-transformed data. Within each food item and sex or age class, means followed by different superscript letters are significantly different ($p \leq 0.05$).

DISCUSSION

Potential Sources of Bias

Bartonek and Hickey (1969), Dirschel (1969), and Swanson and Bartonek (1970) have shown differences in the food composition of esophagi and gizzards in several species of waterfowl, mostly because of differential retention rates of hard and soft food items. Moreover, Beer and Tidyman (1942) showed that gallinaceous birds use small, hard seeds as grit and Mott et al. (1972) suggested that hard parts of insects (e.g., beetle mandibles) may also function as grit in the gizzards of blackbirds.

In view of these findings, we conducted laboratory tests with tricolors and found that relatively soft cultivated grains (rice and sorghum) are fully digested within 2 to 4 hr, whereas harder wild seeds, such as water grass, are only about 50% digested at 8 hr. Small, very hard seeds of species such as smartweed remain completely undigested after 12 hr. Swanson and Bartonek (1970) recommended that only esophageal contents be used in avian food habits studies. Such a method would be impractical for blackbirds because they feed in many different habitats and locations and may consume different foods at different times of the day (Willson 1966). Esophageal contents in our study would largely reflect only those foods eaten just before the birds entered the roost. Stomach contents, on the other hand, would reflect the foods eaten earlier in the day but would contain unrepresentative percentages of those most resistant to digestion.

In calculating the aggregate percent volume of foods eaten for Table 1, we tried to lessen the above sources of bias associated with single-organ analyses by averaging the esophageal and stomach contents together for each bird whose esophagus contained food (all stomachs contained food). The resulting data contain a slight to moderate bias toward stomach contents for each species depending upon the proportion of birds with empty esophagi, but the bias is less than with a single-organ analysis. For tricolors, red-wings, cowbirds, and yellowheads, 65, 77, 74, and 88% of the birds, respectively, had food in the esophagus. Only 11% of the Brewer's blackbirds had food in the esophagus, however, so the data for this species are the most heavily weighted toward stomach contents.

Differential Food Selection

Lack (1954, 1966), Kear (1962), and Schoener (1965) have found that closely related species of birds occupying the same area generally rely on different foods. However, the presence of a super-abundant food supply can mask the feeding differentiation evolved in natural systems (Lack 1954). Brown (1969) has aptly pointed out that the food of wild birds is a compromise between what they prefer and what is available.

In the Sacramento Valley, rice is a super-abundant food for much of the year. In addition to thousands of acres of ripening rice available during late summer and fall, large amounts of waste rice are available in fields during the winter and perhaps into spring. Wild-growing blackbird foods, particularly water grass, are kept at a minimum by the combination of rice monoculture and intensive agricultural weed control programs. It is not surprising, therefore, to find rice as a prominent food in the diet of blackbirds in the area. What is surprising is the large amount of water grass eaten. It appears that cowbirds, and to a lesser extent the other four species, must preferentially select or search for water grass for it to be such a large portion of the annual diet. Despite the abundance of cultivated grains, the many significant differences in food consumption show that the five blackbird species have maintained a large degree of differential food selection. Thus, it appears that mechanisms evolved in natural systems to subdivide the food subniche are still operative, to some degree, in the agricultural environments created by modern man.

The actual mechanisms of feeding differences among bird species have been shown to be related primarily to differences in bill size (which is related to body size) and bill structure, which affect the size of seeds that can be handled efficiently and the ease of catching insects (Kear 1962; Hespenheide 1966; Newton 1967, 1973; Brown 1969; Willson 1971, 1972; Willson and Harmeson 1973). Differences in bill structure and size exist among all five blackbird species we studied and, therefore, offer the best explanation of their feeding differences. The finch-like bill of cowbirds is the most adapted for seed eating, and the longer, thinner bills of red-wings, tricolors, and Brewer's blackbirds are more generalized for some insect gathering (Beecher 1951). Hence, cowbirds ate higher percentages of seeds and fewer insects than did these other three species. Even among congeneric species, bill structure apparently influences the diet. The tricolor has a longer and thinner bill than that of the closely related red-wing (Davis 1954, Orians 1961) and ate more insects than did the latter species. In addition to structure differences, the bills of yellow-heads and red-wings are larger than those of tricolors and Brewer's, whose bills are larger than the cowbirds'. Thus, the cowbird may select more water grass than would the other four species simply because the small water grass seeds are easier for it to handle than the larger seeds of the cultivated grains.

Bill structure and size may also influence the feeding habits of tricolor and red-wing sexes. Selander (1966) found that sex-related feeding differences in woodpeckers (*Centurus* spp) were due to sexual dimorphism of the feeding apparatus. In the tricolor and red-wing, females are smaller than males and have smaller bills (Davis 1954, Orians 1961). This may explain why females ate significantly more of the small wild seeds, and males more of the larger cultivated grains.

Differential habitat utilization may also account for some of the feeding differ-

ences among species and between sexes. Brewer's blackbirds, in particular, are often found loafing and feeding along roadsides and other waste areas, whereas the other four species are most often found in mixed-species flocks near fields, marshes, or riparian situations. In addition, flock segregation by sex, which has been reported at various seasons for yellow-heads (Willson 1966, Crase and DeHaven 1972), red-wings (Meanley 1961, Orians 1961), tricolors (DeHaven et al. 1975), and Brewer's (Bent 1958), may increase intersexual feeding differences if the male and female flocks, with their different bill sizes, forage in different habitats.

Differences in size of bird and structure of bill do not adequately explain the differential consumption of wild seeds and insects by subadult and adult tricolors because the bill and other structures are generally full grown in passerines by the fall and winter months (Marshall 1948, Power 1970). Brown (1969) suggested that young birds may inherit the ability to recognize food by certain cues, such as seed color, size, and shape. However, such instinctual responses could be modified by experience with other available foods (Newton 1973). Therefore, young tricolors might recognize certain wild seeds as food but would have to learn to eat the larger, cultivated grains. Proficiency in catching insects might also be learned in that the more experienced an individual becomes, the more adept he would be at successfully securing a food item that attempts escape.

Relationship To Agriculture

Our study shows changes in the diet of California's red-winged blackbirds since earlier studies by Beal (1900) and Soriano (1931). They reported more wheat and oats than we found; Beal did not mention rice and Soriano found only small amounts. Beal also found a higher proportion of animal matter than we did, but Soriano's figures were similar to ours.

Three factors likely account for most of these differences. First, the acreages of the various grain crops have changed considerably. There was no cultivated rice in California during Beal's studies in the late 1800's, and fewer than 40,500 ha (100,000 acres) in the 1930's. Rice is now one of the dominant grains in the Sacramento Valley (Johnston and Dean 1969). Second, there have been continuing drainage and destruction of natural marsh areas, thereby reducing the availability of native marsh foods. And last, the birds examined by Beal and Soriano were from a larger geographic area and more varied habitats than were the birds we examined.

The diet of Brewer's blackbirds in California as reported by Soriano (1931) was not as strikingly different from our data as that of the red-wing. We found less wheat and filaree but more rice and water grass than did Soriano. Again, differences in study areas and changes in agriculture probably account for most of these differences.

Neff and Meanley (1957) and Meanley (1971) studied the foods of red-wings and cowbirds in a situation similar to ours—the rice fields of Arkansas and Louisiana. Rice was 45% of the red-wing's annual diet in Arkansas and 67% in Louisiana. These proportions are similar to those we found for California red-wings. However, rice was 46% of the brown-headed cowbird's annual diet in Arkansas versus only 26% of our study.

The feeding differences between blackbirds of different species, sexes, and ages mean that some groups are more responsible for agricultural damage than

others. Although we were primarily concerned with rice damage, the feeding differences that we found likely exist in many, if not all, damage situations. Mott et al. (1972), for example, found that red-wing males were responsible for more corn damage in South Dakota than were females. However, selective control of only the "damaging" groups would be practically impossible. Chemical repellents such as methiocarb (Mesurol®) (DeHaven et al. 1971, Guarino 1972, Crase and DeHaven 1976) offer the most promising method of safely protecting crops. Since they simply render the crop unpalatable, they do not harm those birds not causing damage and those that may actually be helping the farmer by consuming large numbers of insects throughout much of the year.

ACKNOWLEDGMENTS

We thank W. Harry Lange and Lynn J. Shaw, University of California, Davis, for help in the identification of insects and in the computer analysis of the data, respectively. Bruce M. Browning, California Department of Fish and Game, identified many of the seeds. We also thank co-workers Richard R. West, Paul P. Woronecki, Joseph L. Guarino, Willis C. Royall, Jr., Jerome F. Besser, and Ann H. Jones for help during various phases of the project.

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Calif. Fish and Game 64(4): 268-279 1978

THE INFAUNA OF A SUBTIDAL, SAND-BOTTOM COMMUNITY AT IMPERIAL BEACH, CALIFORNIA [1]

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The infauna characteristic of shallow subtidal sand bottoms was surveyed seasonally during 1976 at Imperial Beach, California. A total of 5,916 individuals was collected and 131 species were represented. Among the most important contributors to the density were the amphipods, *Eohaustorius washingtonianus* and *Paraphoxus epistomus*, the isopod, *Ancinus granulatus*, the gastropod, *Olivella baetica*, and the sand dollar, *Dendraster excentricus*. Comparison of current community composition with that of a previous study indicates considerable stability or persistence of the fauna.

INTRODUCTION

Although subtidal sand habitats are extensive along the southern California coastline, the inshore sand habitat is not well studied, probably because of the difficulty of sampling within the surge zone. Fager's (1968) study is the only published quantitative account of a shallow water epifaunal sand community in southern California. A major survey of the southern California mainland shelf was undertaken by the Allan Hancock Foundation in 1959 in cooperation with several State of California agencies. Although the major emphasis of that study concerned the offshore fauna on the continental shelf, some samples were taken in the inshore environment (California State Water Quality Control Board 1965; Jones 1969; Southern California Coastal Water Research Project 1973). Only a few samples were taken at any one locality, but some information is available on infaunal organisms living at depths of 3 to 10 m along the southern California coastline.

The present study was part of a larger survey of the marine communities located at Imperial Beach, California (Dexter 1977), which was conducted for the U.S. Army Corps of Engineers (Project DAC 09-76-M-1323). The subtidal sand sediment was found to contain a diverse and persistent community of organisms which was maintained seasonally and spatially.

METHODS

Four transects were selected as sampling sites in the subtidal sands off Imperial Beach. These transects were identified as Elkwood, Surfside, Carnation, and Radio. Elkwood transect was located at the foot of Elkwood Street about 100 m south of the Imperial Beach Pier. Surfside, at the foot of the Surfside Motel, was located about 175 m north of the Imperial Beach Pier. Carnation, at the foot of Carnation Street, was located between two existing intertidal rocky groins, and about 500 m north of the Imperial Beach Pier. Radio was located about 750 m north of the Imperial Beach Pier off the U.S. Naval Radio Facility.

The transects were sampled seasonally during 1976 at depths of 3, 4, 5, 6, and 7.5 m (surge conditions permitting). Winter sampling was conducted on January

[1] Accepted for publication January 1977.

31 and February 1; spring samples were collected on April 24; summer samples on July 21; and fall samples on October 17. The subtidal sand fauna was surveyed quantitatively by divers using scuba and an airlift sampler (Chess 1969). The airlift sampler is a diver-operated vacuum collecting device for sampling the benthic macrofauna. The winter samples were obtained using a Nitex vacuum bag of 760-μ mesh while later samples were obtained with a vacuum bag of 1,000-μ mesh. This change was made because of the extensive time required to sort the collections made with the smaller mesh bags.

A stainless steel cylinder 0.25 m^2 in circular surface area was pushed into the sand at each station. The airlift sampler was used to remove all sediment to a depth of 20 cm below the surface within the cylinder. A small sediment core was taken to a depth of 10 cm at each station for sediment analysis.

The sediment and organisms retained in the vacuum bags were preserved in a 5% solution of formalin in seawater. In the laboratory the organisms were sorted to major phyla and blotted wet weights were determined for each major group. The organisms were identified to species and number of individuals of each were counted. Sediment grain size was analyzed with an Emery settling tube (Emery 1938).

On October 17, 1976, a separate collection was made to sample the size-frequency distribution of the sand dollar, *Dendraster excentricus,* which was not accurately sampled with the airlift sampler. A stainless steel cylinder 0.1 m^2 in surface area was pushed into the sand in the section of the sand dollar bed along each transect where density of individuals was highest. All individuals of *D. excentricus* within each sample were removed and later their length was measured to the nearest mm. The length was determined as the distance from margin to margin of the test in a line through III_A, the apical system, and lunule 5_l.

Species diversity was determined using the Shannon-Wiener diversity index (Lloyd and Ghelardi 1964) for each transect during each season (all depths combined), for each depth at each season (all transects combined), and for each seasonal collection (data pooled for all transects and all depths within a given season). Coefficients of community (Whittaker 1956) were calculated to compare between transect, between depth, and within transect similarity for within season and between season samples. The coefficient of community, an expression of the degree of similarity between two or more samples, ranges from 0 for samples having no species in common to 1.0 for samples identical both in species composition and in quantitative value for the species.

RESULTS

A total of 60 quadrats was collected from a sample area of 15.0 m^2, from which 5,916 individuals representing 131 species were collected. The average density of the fauna was 394/m^2. The total wet weight of the collected organisms was 446.7 g, averaging 29.8 g/m^2.

Complete data for individual samples along all transects during all seasons are presented by Dexter (1977) in the technical report which is available at the San Diego State University library.

The fauna was dominated by polychaetes and arthropods which contributed 53% and 26%, respectively, of the total number of individuals (Table 1). In addition, more than 70% of the species were in these two taxonomic groups. The echinoderms, particularly *Dendraster excentricus,* were the largest contribu-

tor to the biomass, forming 44% of the total; the second major contributors to biomass were the arthropods, which composed 26% of the total.

TABLE 1. Faunal Composition of Subtidal Sands off Imperial Beach, California, Based on Seasonal Sampling in 1976.

Taxon	*Number of individuals*	*Density (no./m²)*	*Occurrence (no./60 quadrats)*	*Percent composition*
Cnidaria				
Renilla kollikeri	3		3	
Nemertea	269	17.9	44	4.55
Sipunculida	4		1	
Polychaeta				
Anaitides multiseriata	1		1	
Aricidea sp	7		4	
Axiothella rubrocincta	2		1	
Capitellidae	7		2	
Capitita ambisecta	1		1	
Chaetozone corona	12		9	
Chaetozone sp	4		2	
Chone mollis	2		4	
Glycera capitata	11		5	
Glycera sp	7		6	
Glycera tenuis	30	2.0	18	
Glycera tesselata	5		3	
Glycinde armigera	1		1	
Goniada littorea	85	5.7	21	1.44
Hemipodus borealis	2		2	
Hesperone sp	3		2	
Lumbrineris pallida	91	6.1	29	1.54
Lumbrineris tetraura	9		7	
Magelona pitelkai	182	12.1	42	3.08
Nephtys caecoides	75	5.0	29	1.27
Nephtys californiensis	18	1.2	6	
Nephtys sp	3		3	
Nereis latescens	5		2	
Notomastus tenuis	43	2.9	9	
Onuphis vexillaria	59	3.9	27	1.00
Ophelia limacina	1		1	
Ophiodroma pugettensis	5		4	
Owenia collaris	1		1	
Pareurythoe sp	25	1.7	9	
Pectinaria californiensis	7		5	
Pista elongatus	1		1	
Polydora sp	1		1	
Polynoidae	20	1.3	8	
Prionospio cirrifera	7		5	
Prionospio pygmeus	67	4.5	18	1.13
Rhynchospio arenicola	172	11.5	32	2.91
Scolelepis acuta	101	6.7	24	1.71
Scolelepis folliosa	1		1	
Scoloplos armiger	209	13.9	27	3.53
Sigalionidae	1		1	
Spiophanes missionensis	2		2	

Sthenelais verruculosa	10		6	
Thalanessa spinosa	142	9.5	32	2.40
Tharyx multifilis	3		2	
Typosyllis armillaris	3		2	
Typosyllis sp	43	2.9	11	
Mollusca, Gastropoda				
Acteocina harpa	1		1	
Astrea gibberosa	1		1	
Balcis sp	2		2	
Bittium sp	2		2	
Caecum californicus	1		1	
Crepidula sp	3		1	
Mitrella carinata	3		2	
Nassarius fossatus	39	2.6	8	
Nassarius perpinguis	2		2	
Olivella baetica	222	14.8	18	3.75
Olivella biplicata	18	1.2	12	
Ophiodermella sp	1		1	
Polinices reclusiana	47	3.1	18	
Turbonilla regina	1		1	
immature gastropod A	4		4	
nudibranch A	1		1	
Mollusca, Bivalvia				
Bornea retifera	16	1.1	4	
Chione californiensis	1		1	
Cryptomya californica	177	11.8	11	2.99
Donax gouldii	7		3	
Entodesma saxicola	1		1	
Lucina nuttallii	1		1	
Macoma sp A	1		1	
Macoma sp B	10		3	
Macoma sp C	1		1	
Mytellidae	1		1	
Siliqua lucida	1		1	
Solen sicarius	3		2	
Tellina bodegensis	1		1	
Tellina carpenteri	53	3.5	16	
immature sp A	4		2	
immature sp B	4		3	
immature sp C	1		1	
Echinodermata, Echinoidea				
Dendraster excentricus	209	13.9	31	3.53
Echinodermata, Ophiuroidea				
Amphipodia digitata	24	1.6	12	
Amphipodia occidentalis	4		4	
Amphipodia urtica	7		3	
Echinodermata, Holothuroidea				
Synaptidae	3		1	

Hemichordata				
Saccoglossus	11		9	
Arthropoda, Pycnogonida				
species A	2		2	
species B	1		1	
species C	1		1	
Arthropoda, Crustacea				
Copepoda	3		3	
Ostrocoda				
Euphilomedes carcharodonta	456	30.4	18	7.71
Mysidacea				
Archeomysis maculata	58	3.9	17	
unidentified	1		1	
Cumacea				
Diastylopsis tenuis	133	8.9	19	2.25
Leptocuma forsmani	163	10.9	40	2.76
Isopoda				
Ancinus granulatus	275	18.3	32	4.65
Edotea sublittoralis	11		7	
Halisphasma geminata	3		2	
Idothea fewkewsi	1		1	
Synidotea harfordi	1		1	
Synidotea sp n	3		1	
Amphipoda				
Amphithoe sp	1		1	
Aorides columbiae	10		3	
Atylus tridens	94	6.3	20	1.59
Caprellidae	1		1	
Elasmopus sp	1		1	
Eohaustorius washingtonianus	1029	68.7	34	17.39
Gammaropsis thompsoni	1		1	
Hyalidae	4		1	
Listriella melanica	2		1	
Mandibulophoxus gilesi	242	16.1	24	4.09
Megaluropus longimerus	2		1	
Paraphoxus epistomus	421	28.1	52	7.12
Photis californica	1		1	
Photis sp	2		2	
Synchelidium shoemakeri	43	2.9	15	
Synchelidium sp	2		1	
Decapoda, Natantia				
Alpheus dentipes	3		3	
Urocaris infraspinis	46	3.1	7	
Decapoda, Reptantia				
Blepharipoda occidentalis	1		1	
brachyuran megalops	6		6	
Callianassa gigas	32	2.1	17	
Cancer gracilis	2		2	
Cancer jordani	16		7	
Holopagurus pilosus	7		5	
Lepidopa myops	48	3.2	31	
Pinnixa barnharti	101	6.7	16	1.71
Pinnixa sp	64	4.3	8	1.08
Portunus xantusi	1		1	

Of the 131 species present, only 24 individually contributed 1% or more of the composition by density. Eight of these also occurred in 50% or more of the quadrats. These dominant species include the polychaetes *Magelona pitelkai*, *Rhynchospio arenicola*, and *Thalanessa spinosa*; the sand dollar, *Dendraster excentricus*; the cumacean, *Leptocuma tenuis*; the isopod, *Ancinus granulatus*; and the amphipods, *Eohaustorius washingtonianus* and *Paraphoxus epistomus*. Five additional species had a density greater than 10/m², but occurred less frequently: the polychaete, *Scoloplos armiger*, the bivalve, *Cryptomya californica*, the gastropod, *Olivella baetica*; the ostrocod, *Euphilomedes carcharodonta*; and the amphipod, *Mandibulophoxus gilesi*. These 13 species comprised 70% of all individuals collected from the subtidal sands off Imperial Beach.

The sand dollar, *Dendraster excentricus*, was the largest contributor to the biomass of the subtidal sand fauna. Although the density of *D. excentricus* averaged 14/m² throughout the study area, the average density within the sand dollar bed was 1,210/m². The airlift sampler collected only smaller individuals (Figure 1). Size frequency distributions of organisms collected by hand (Figure 1) show changes in population size structure along Imperial Beach. There was no significant difference in the mean size of sand dollars along the Radio and Carnation transects, but a significant decrease ($p < 0.001$) in the mean size of the population occurred from the southernmost transect to these northernmost transects, based on the results of a Kólmogorov-Smirnow two sample test (Siegel 1956).

Synthesis of the number of species found, density of individuals, biomass, median sediment grain size, and the Shannon-Wiener diversity index in relation to transect location and depth were conducted (Table 2). No obvious differences in community structure are evident among the four transect locations. However, there are clear differences in the structure of the community with depth. The major changes include an increase in the number of species, an increase in the density of individuals, and an increase in diversity (as measured by the Shannon-Wiener index) with increasing depth. Sediment particle size decreased with increasing water depth, but at all depths can be classified as fine or very fine sand.

A summary of the coefficient of community values indicating similarity between samples was computed (Table 3). Indices of similarity averaged 0.2409 for within transect similarity and 0.3173 for between depth similarity, indicating greater differences within a transect than between depths during the same season. When the data from each seasonal sample were compared to all other seasonal samples (between season variation), the average coefficient of community was 0.4559. A relatively high seasonal similarity of 46% in faunal composition and abundance indicates that a single community of organisms occurred throughout the study area.

DISCUSSION

Community Composition

Thirteen species were characteristic of the subtidal sand fauna. The haustoriid amphipod, *Eohaustorius washingtonianus,* was the most abundant species in the Imperial Beach subtidal sand community. It was found from the low intertidal

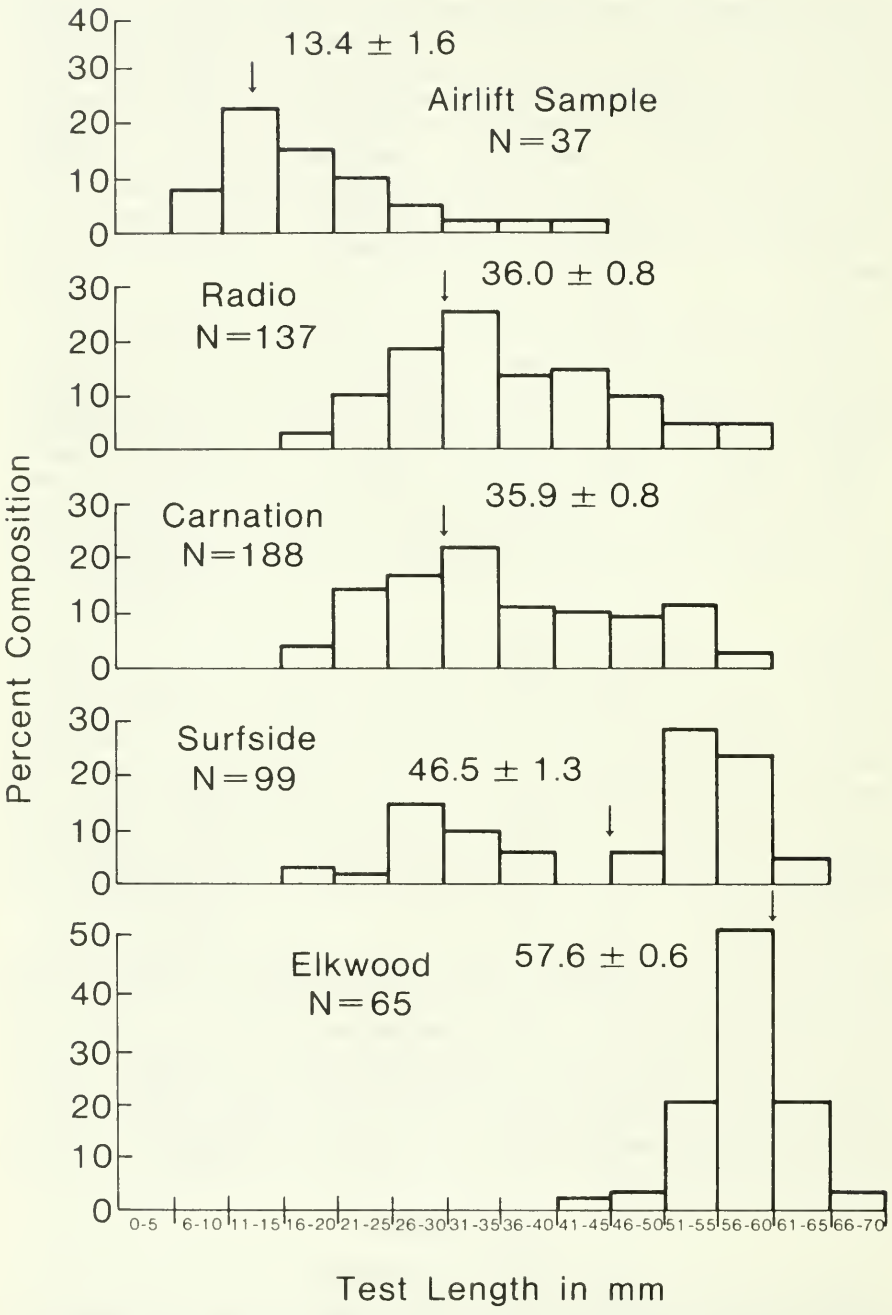

FIGURE 1. Size frequency histograms of *Dendraster excentricus* collected along each transect on October 17, 1976, compared to total sample collected October 17 with airlift sampler. Mean size and standard error are indicated.

TABLE 2.

A. Comparison of Shannon-Weiner Diversity Index Between Transect Locations and Between Depths During 1976 at Imperial Beach, California.

Season	*Depth in meters*				*Transect locations*			
	3.0	*4.5*	*6.0*	*7.5*	*Elkwood*	*Surfside*	*Carnation*	*Radio*
Winter	n.s.	3.78	4.37	4.03	4.24	3.98	4.37	4.20
Spring	n.c.	n.c.	n.c.	4.58	n.c.	n.c.	4.13	n.c.
Summer	n.c.	3.98	4.25	4.70	4.16	4.34	4.83	5.03
Fall	n.c.	2.50	4.05	3.55	4.10	4.13	3.58	3.65

n.s. = not sampled. n.c. = not calculated. Diversity index was not calculated when less than 200 individuals were collected in a sample.

B. Comparison of Number of Species Present Between Transect Locations and Between Depths.

Season	*Depths*				*Transect locations*			
	3.0	*4.5*	*6.0*	*7.5*	*Elkwood*	*Surfside*	*Carnation*	*Radio*
Winter	n.s.	40	48	56	38	45	44	47
Spring	11	27	23	50	38	35	43	28
Summer	22	40	54	45	36	54	38	43
Fall	38	39	48	36	38	39	48	36

C. Comparison of Density of Individuals (no./m²) Between Transect Locations and Between Depths.

Season	*Depths*				*Transect locations*			
	3.0	*4.5*	*6.0*	*7.5*	*Elkwood*	*Surfside*	*Carnation*	*Radio*
Winter	n.s.	891	671	916	348	1411	760	785
Spring	45	135	91	489	158	147	336	119
Summer	122	280	364	301	129	394	300	244
Fall	175	350	249	837	404	365	508	334

D. Comparison of Biomass (grams/m²) Between Transect Locations and Between Depths.

Season	*Depths*				*Transect locations*			
	3.0	*4.5*	*6.0*	*7.5*	*Elkwood*	*Surfside*	*Carnation*	*Radio*
Winter	n.s.	116.5	48.1	24.4	34.8	70.5	82.3	64.4
Spring	3.0	69.0	7.6	127.0	43.1	11.6	60.8	11.4
Summer	24.5	7.0	12.5	15.5	14.5	13.0	22.4	9.7
Fall	2.8	9.5	26.7	32.2	22.4	20.8	19.9	8.1

E. Comparison of Sediment Median Grain Size in Microns Between Transect Locations and Between Depths.

Season	*Depths*				*Transect locations*			
	3.0	*4.5*	*6.0*	*7.5*	*Elkwood*	*Surfside*	*Carnation*	*Radio*
Winter	142	123	113	115	135	115	117	122
Spring	188	184	126	128	160	180	146	139
Summer	165	185	134	121	113	151	165	176
Fall	163	159	123	90	108	125	146	130

seaward, but only became abundant at 4.5 m or deeper. The species is distributed along the southern California coastline (Barnard 1957).

Along the eastern coast of the United States, both in intertidal and subtidal sand communities, haustoriid amphipods dominate the sand communities (Croker 1967; Dexter 1967, 1969, 1971; Croker, Harger, and Scott 1975; Holland

TABLE 3. A Comparison of Coefficients of Community for the Subtidal Sand Fauna at Imperial Beach, California.

A. Similarity within transects

Season	*Elkwood*	*Surfside*	*Carnation*	*Radio*
Winter	.1751	.3437	.3712	.3910
Spring	.1724	.1733	.2406	.1741
Summer	.1860	.2371	.2185	.1781
Fall	.2531	.2428	.2688	.2551

B. Similarity between depths

	3.0 m	*4.5 m*	*6.0 m*	*7.5 m*
3.0 m	x			
4.5 m	.3621	x		
6.0 m	.2399	.4217	x	
7.5 m	.1694	.3058	.3672	x

C. Similarity within transects

	Elkwood	*Surfside*	*Carnation*	*Radio*
Elkwood	x			
Surfside	.4738	x		
Carnation	.4371	.5319	x	
Radio	.3886	.5826	.5253	x

D. Similarity between seasons

	Winter	*Spring*	*Summer*	*Fall*
Winter	x			
Spring	.3768	x		
Summer	.4728	.3103	x	
Fall	.4774	.4757	.6221	x

and Polgar 1976; Sameoto 1969*a*, 1969*b*). West coast studies have not shown haustoriid amphipods to be important members of the intertidal beach community, except in some tropical beaches (Dexter 1974). Their contributions to the subtidal sand communities are not well documented, perhaps due to the scarcity of pertinent studies. Much more attention should be focused on these abundant, filter feeding amphipods and their role in the shallow subtidal sands along the southern California coastline should be determined.

Two other dominant species were also amphipods, *Paraphoxus epistomus* and *Mandibulophoxus gilesi*, both of which belong to the family Phoxocephalidae. Phoxocephalid amphipods are characteristic of both intertidal and subtidal sand substrates. *P. espistomus* occurs in the western Atlantic Ocean and in the eastern Pacific Ocean from Puget Sound to the Gulf of California (Barnard 1960). At Imperial Beach its abundance increased with depth. *M. gilesi* has an interesting geographical distribution, occurring both in the Indian Ocean along Sri Lanka and the Madras coast and along the southern California coastal shelf (Barnard 1960). At Imperial Beach, *M. gilesi* was aggregated in the surge zone at 4.5 m.

The largest contributor to the biomass at Imperial Beach was the sand dollar, *Dendraster excentricus*. This filter feeding echinoid occurs in the eastern Pacific Ocean from Baja California to Alaska; several aspects of its biology have been

studied (Niesen 1969; Merrill and Hobson 1970; Birkeland and Chia 1971; Timko 1975). At Imperial Beach, *D. excentricus* was most abundant in the surge zone. Observations on the size structure of *D. excentricus* (Figure 1) indicate that successful recruitment has occurred continuously during the past several years at Imperial Beach. Timko (1975) estimates that *D. excentricus* reach an average diameter of 21 mm at 1 year of age, 32 mm at 2, 47 mm at 3, and that individuals 4 years or older are 60 mm or larger. If her estimates of age are correct, then successful recruitment of new individuals has occurred yearly from 1972 through 1975 in the areas of Radio and Carnation transects, and in 1972, 1973, and 1975 at Surfside. Recruitment in the area of the Elkwood transect apparently was successful only in 1972 and 1973. Current observations from airlift samples indicate the presence of the 1976 age class along all transects. However, future studies would have to be conducted to determine whether this age class persists and is successful. The aggregations of *D. excentricus* at Imperial Beach are the largest seen by the biologists involved in this study at any location in San Diego County over the past 10 years.

Four polychaetes were among the most abundant species. They are: *Magelona pitelkai* (Magelonidae), *Rhynchopsio arenicola* (Spionidae), *Scoloplos armiger* (Orbiniidae), and *Thalanessa spinosa* (Sigalionidae). Hartman (1969) reports that *S. armiger* occurs in littoral depths off southern California and western Europe; *M. pitelkai* and *R. arenicola* are common in central and southern California. *T. spinosa* is also distributed along central and southern California (Hartman 1968). Magelonid and spionid polychaetes are surface deposit feeders while orbiniids directly ingest the substrate as they burrow. *M. pitelkai, R. arenicola,* and *T. spinosa* increased in abundance with depth at Imperial Beach, while *S. armiger* had its peak abundance in the surge zone.

The isopod, *Ancinus granulatus,* was most abundant in the subtidal sand at Imperial Beach but also occurred in the intertidal. *A. granulatus* occurs along the California coast and in the Gulf of California (Glynn and Glynn 1974). Although species of *Ancinus* are among the most abundant species in tropical American beach communities (Dexter 1972, 1974), they have not been reported as abundant in temperate American beaches.

The cumacean, *Leptocuma forsmani,* was distributed from the surf zone outward and increased in abundance with depth. *L. forsmani* occurs along the western coast of North America (Zimmer 1943). The ostrocod *Euphilomedes carcharodonta* was very abundant in the winter samples when the smaller mesh collecting bag was used. During the remainder of the study, when the 1,000-μ mesh bag was used, the species was collected infrequently. The majority of individuals were collected from the surge zone. *E. carcharodonta* is found along the coast of California to Canada (Smith 1952). Presumably, when more work is done on the meiofauna of the subtidal sands, the contributions of this species will be recognized.

The gastropod, *Olivella baetica,* occurs from southern Alaska to Baja California (Morris 1966) and at Imperial Beach was most abundant in the surge zone. The bivalve, *Cryptomya californica,* occurs from Alaska to northern Peru (Keen 1971) and is often associated with burrowing shrimp. At Imperial Beach its abundance increased with depth.

Faunal Similarity

Based on the results of this study, the fauna of the subtidal sands off Imperial Beach can be considered as a single community. Highest similarity in faunal composition and abundance occurred between transects; lower similarity was observed between depths. The lowest coefficients of community were seen when within transect stations were compared. Similarity values within and between depths were comparable for each sample date and for seasonal samples, indicating no marked seasonal change. Discrete communities were not present, but a continuum of changes occurred through both season and space.

The fauna of the Imperial Beach subtidal sands is typical of the inshore area of southern California. San Diego Gas and Electric (1973) lists only 19 species of invertebrates occurring in a similar sand bottom area at depths of 7.5 m or less off the Encina Power Plant, Carlsbad, California, of which nine were shared in common with the study site described here. The California State Water Quality Control Board (1965) lists a total of 61 species of invertebrates taken in 3 to 10 m of water in the sandy subtidal along the coastline of California. Of these, 14 species were collected at Imperial Beach in the present study, and 23 additional genera were shared in common by the two studies.

Stability of Faunal Composition

The composition of the infauna off Imperial Beach is quite stable or persistent. In 1959, a single Van Veen grab sample was taken in 9 m of water off Imperial Beach (Station #6418-59; California State Water Quality Control Board 1965). A total of 40 species was taken, of which all but six genera and three unidentified species (representing only 9% of all the individuals) also were collected during the present Imperial Beach study. The dominants in 1959 included three polychaetes (*Goniada littorea, Prionopsio malmgreni,* and *Spiophanes bombyx*), one gastropod (*Olivella baetica*), one bivalve (*Tellina buttoni*), one cumacean (*Diastylopsis tenuis*), and two amphipods (*Paraphoxus bicuspidatus* and *P. epistomus*). Two of these species were among the 13 dominant species in 1976, two other species were collected in 1976, and three additional genera were shared in common. Considering that the samples were made 17 years apart, with different sampling techniques, and at slightly different water depths, the similarity in the fauna is remarkable. Thus, the evidence obtained in this study indicates that the subtidal sands off Imperial Beach contain a stable and diverse fauna.

ACKNOWLEDGMENTS

Persons providing technical assistance in field and laboratory work and those responsible for species identification are listed in the technical report (Dexter 1977). The manuscript has benefited from critical examination by R. F. Ford. Contribution No. 30 from San Diego State University, Center for Marine Studies.

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Calif. Fish and Game 64(4): 280–301 1978

CALIFORNIA OCEAN SHRIMP MESH EXPERIMENT [1]

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Shrimp net mesh size data obtained from a Department cruise made in 1956 between Point Reyes and the mouth of the Russian River, California, were re-examined. A proportional sampling scheme was used to obtain the maximum likelihood estimator (MLE) of the catch ratio. A comparison of shrimp escapement between five beam trawl cotton nets of different mesh sizes was made. Mesh sizes of five nets, after shrinkage, were 3.6, 4.1, 4.2, 4.3, and 4.7 cm (1.43, 1.60, 1.62, 1.66 and 1.84 inches), respectively. An average escapement rate (AER) for any age group was derived and used to compare differences between the test mesh sizes. AER's for mesh sizes 3.4, 3.8, and 3.9 cm (1.34, 1.50, and 1.55 inches) were estimated. Also, comparisons of catch per hour adjusted by the footage of head rope (CHF) were made of four commercial otter trawl nylon nets with mesh sizes ranging from 3.7 to 3.9 cm (1.44 to 1.54 inches). The mesh size of 3.8 cm (1.50 inches) is recommended.

INTRODUCTION

Ocean shrimp, *Pandalus jordani*, support one of the youngest commercial fisheries of California (Dahlstrom 1972). Commercial quantities of this species were first fished off Morro Bay in April 1952. Thereafter, two other major shrimp beds along the California coast were fished. Three regulatory areas were designated and catch quotas established for each (Figure 1). Mesh size regulations were imposed and catch quotas and a season were established.

Area A contains the largest shrimp bed and produces most of the shrimp landed in California. Shrimp landings in Area A climbed from 340,000 kg (750,000 lb) in 1957 to 840,000 kg (1.86 million lb) in 1963. Catches declined to under 450,000 kg (1 million lb) in 1964, but increased to the peak of 1.63 million kg (3.6 million lb) in 1970. This was followed by a short term decline to less than 450,000 kg (1 million lb) in 1973. Catches for 1974 and 1975 were 910,000 kg (2 million lb) and 1.55 million kg (3.4 million lb), respectively.

In the early years of the fishery, fishermen were limited to beam trawls with a minimum mesh size of 2.9 cm (1⅛ inches). In 1958 the minimum mesh size was increased to 3.8 cm (1½ inches) stretch measured inside the knots, and in 1975 the minimum mesh size was reduced to 3.5 cm (1⅜ inches). Otter trawls have been legal since 1962.

These mesh size regulations had been imposed to reduce fishing mortality on small shrimp. Shrimp dealers were usually reluctant to buy small shrimp because of low yield. As a result, small shrimp were discarded. In addition, ocean shrimp are protandric (hermaphroditic) i.e., most individuals function first as males, then as females. About 33 to 50% of the 1-year-old shrimp develop into females without first functioning as males (Geibel and Heimann 1976). Therefore a minimum legal mesh size which permits escapement of most 1-year-old shrimp would insure an adequate spawning stock.

While the California Department of Fish and Game has maintained mesh size regulations from the inception of the fishery, the Oregon Fish and Wildlife Commission has not had shrimp mesh size restrictions since 1970. This action,

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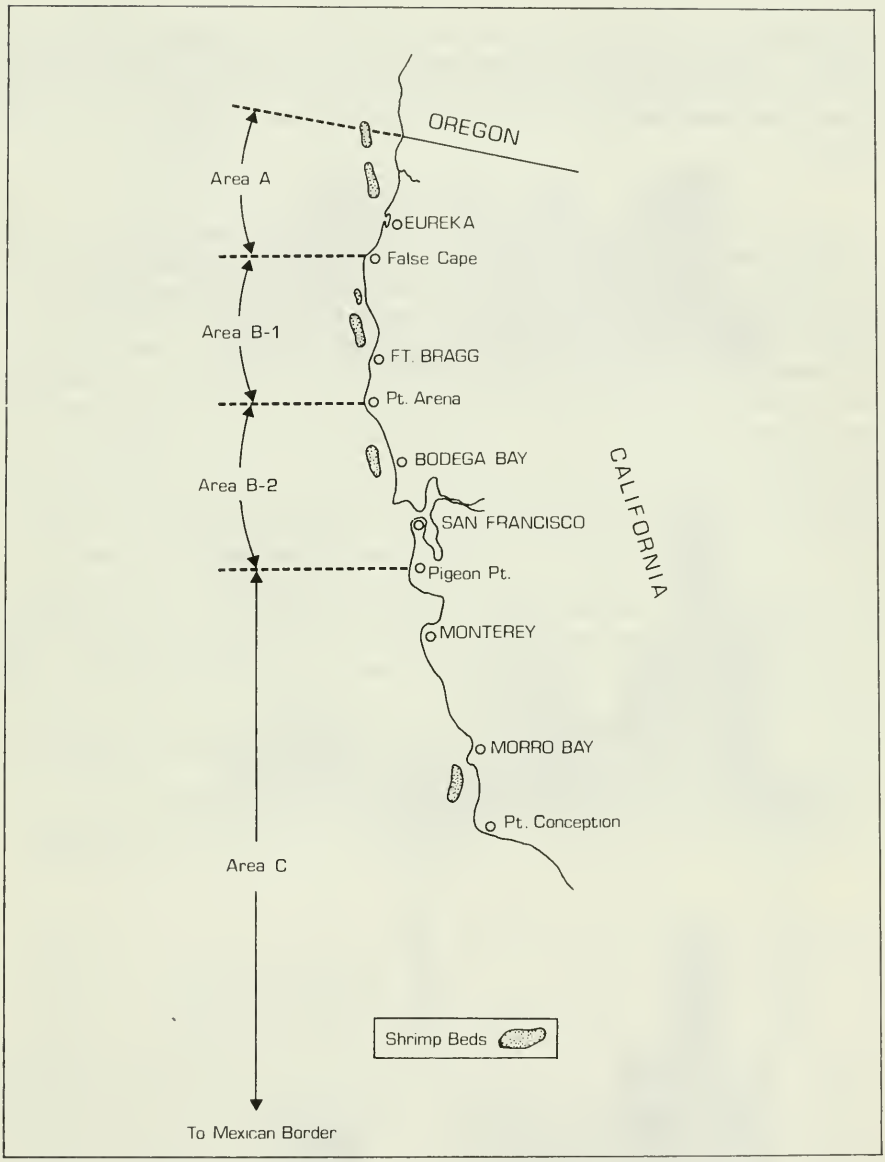


FIGURE 1. Fishing areas for ocean shrimp for California (courtesy of Dahlstrom).

and the sharp decline in landings in 1973, have made re-examination of the effect of mesh sizes on shrimp escapement necessary.

Department marine biologists conducted experiments with nets of different mesh sizes aboard the research vessel *N.B. Scofield* from 26 April to 4 June 1956 (cruise 56-B-1) to compare shrimp escapement through different sizes of mesh. No definitive conclusions had been drawn from these experiments. The purpose

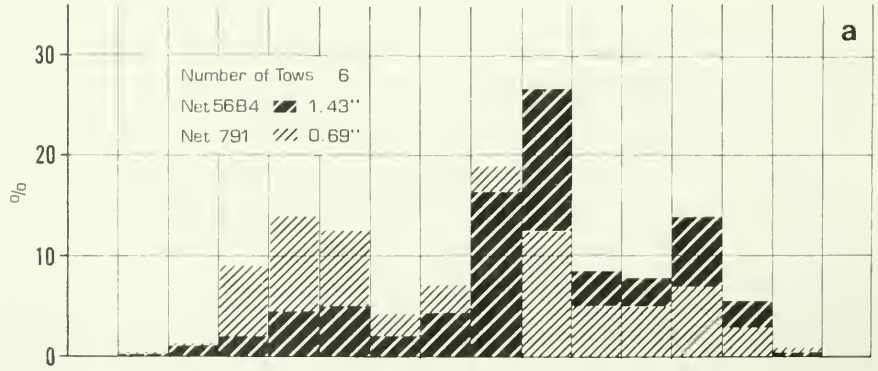
of this paper is to report on my examination of the data from the 1956 shrimp cruise. I conducted a more thorough analysis so as to utilize the information efficiently and to obtain meaningful comparisons of the shrimp escapements between the larger meshes and a control net with mesh size of 1.8 cm (0.69 inches).

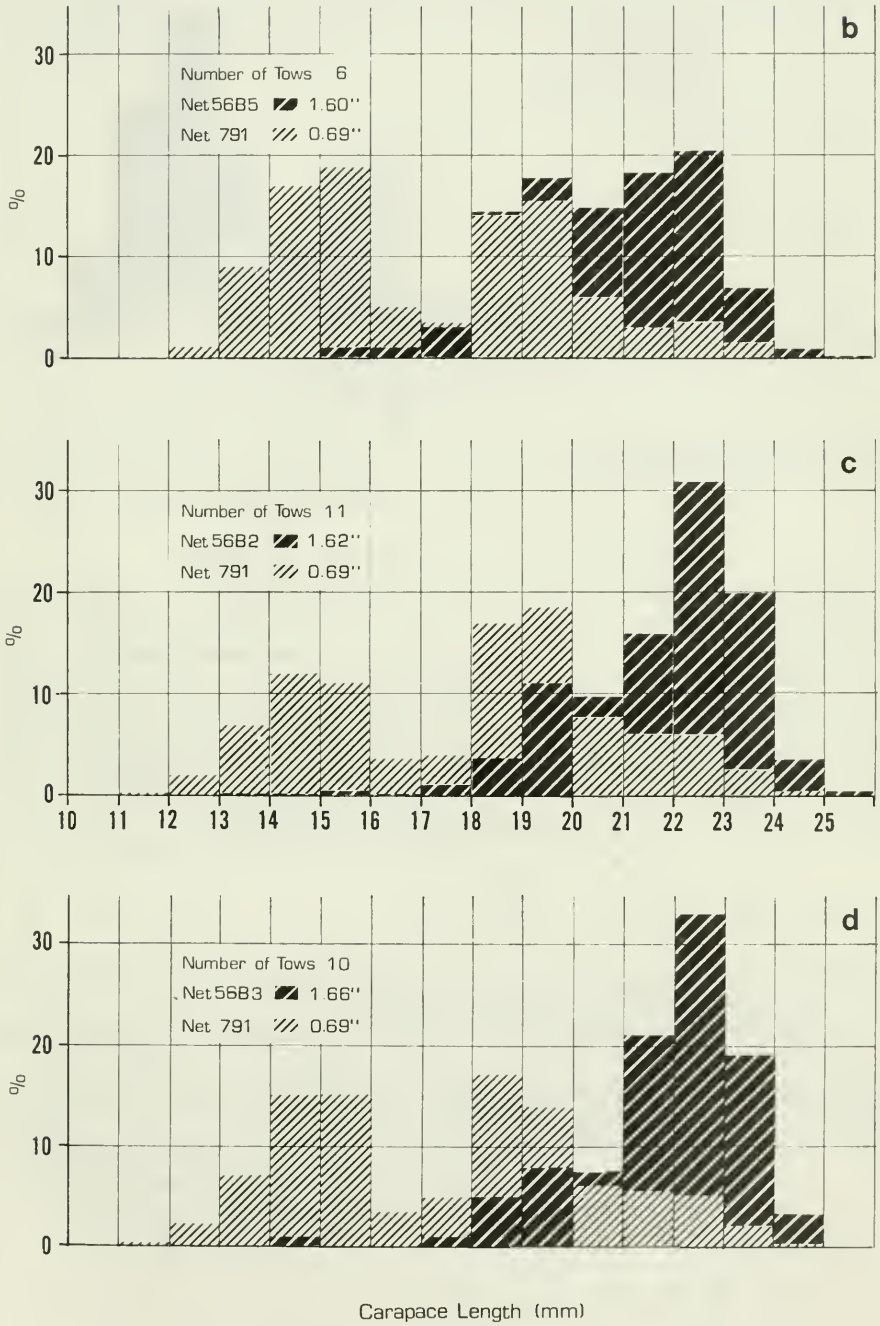
1956 SHRIMP CRUISE

A 6-m (20-ft) beam trawl with a single cross bar was used during the 1956 cruise. For most of the mesh size comparisons, two trawl nets each 3 m (10 ft) across at the mouth were hung side by side and fished for about 30 min. This method should have eliminated bias created by the tendency of the shrimp to school by size even within the same bed. Scouting began off Point Reyes and continued northward until commercial quantities of shrimp were encountered just south of the mouth of the Russian River in 73 m (40 fm). Once shrimp had been located, a total of 100 trawls was made using nets with six different mesh sizes (0.69-control, 1.43, 1.60, 1.62, 1.66, and 1.84 inches). These mesh sizes were stretch measurements between knots (Table 1). Biologists took length frequency samples from 65 trawls in which sufficient quantities of shrimp occurred. Each sample consisted of approximately 100 length measurements of shrimp caught by the test net and an equal number of lengths from the control net. In the original analysis, length frequency samples from each net were combined and compared with the corresponding combined samples from the control nets (Figure 2). No further analyses were made on shrimp catch ratios from test nets.

TABLE 1. Mesh Size and Thread Measurements of the Tested Nets and Control Nets Used in 1956 Shrimp Survey

Manufacturer measurements (inches)	*Measurements after shrinkage (inches)*	*Thread*
0.75	0.69	12
1.50	1.43	12
1.75	1.60	27
1.88	1.62	36
2.00	1.66	36
2.25	1.84	36





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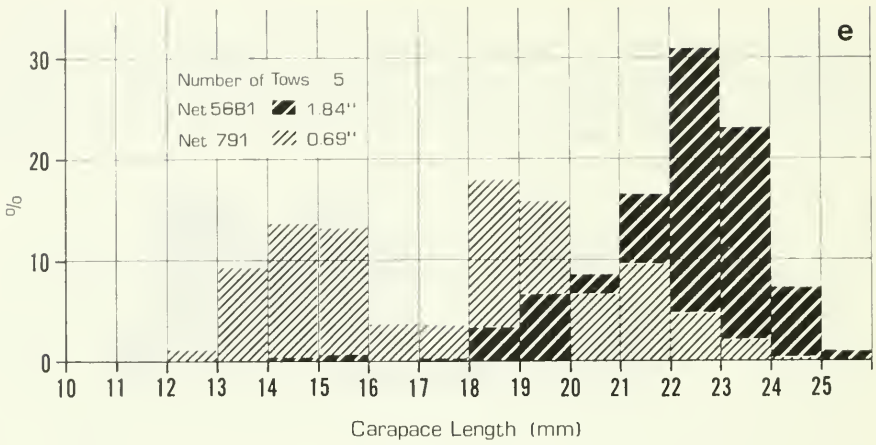

NOTE: all bars begin at 0%

FIGURE 2. 1956 shrimp experiment length relative frequencies (LRF).

REVISION OF THE SAMPLING SCHEME

The original sampling scheme required a sample of 100 shrimp (or all shrimp if less than 100 had been caught) from each net for each tow regardless of the actual catch. A length relative frequency (LRF) was then constructed (Figure 2). The LRF's showed the difference in shrimp length distributions between test net and control net. However, it was impossible to estimate the percentage of shrimp of a particular length or year class that had escaped without information on the actual total catches of each tow. In order to do so, one needed first to estimate the catch ratio γ_{ij} for the mesh size i, i = 1, 2, 3, 4, 5 and shrimp length j, j = 11, 12, ... , 25. γ_{ij} is defined in term of the catches as:

$$\gamma_{ij} = \frac{\mu_{ij}}{\mu_{cj}} = \frac{\mu_{i\cdot} P_{ij}}{\mu_{c\cdot} P_{cj}} = \frac{T_{i\cdot} P_{ij}}{T_{c\cdot} P_{cj}} = q_i \, \theta_{ij} \qquad (1)$$

where γ_{ij} is the ratio of the mean catch per tow of shrimp of length j by the test net i to that of control net c,

μ_{ij} is the expected catch per tow of shrimp of length j by the test net i,

μ_{cj} is the expected catch per tow of shrimp of length j by the control net c towed side by side with the test net i,

$T_{i\cdot}$ is the expected total catch by the net i during the survey, i.e. $T_{i\cdot} = m_i \mu_{i\cdot}$ where m tows are made during the survey,

P_{ij} is the expected percentage of shrimp caught by the net i that are of length j

$$q_i = \frac{T_{i\cdot}}{T_{c\cdot}} = \frac{\mu_{i\cdot}}{\mu_{c\cdot}} \text{ and } \theta_{ij} = \frac{P_{ij}}{P_{cj}}$$

The total catch ($T_{i\cdot}$'s) and percentage of certain shrimp size (P_{ij}) of equation (1) are estimated as follows:

$T_{i\cdot}$ is estimated by

$$N_{i\cdot} = \sum_{k=1}^{m_i} N_{i(k)} \tag{2}$$

and $\mu_{i\cdot}$ is estimated by

$$\hat{\mu}_{i\cdot} = \frac{N_{i\cdot}}{m_i}$$

where $N_{i(k)}$ is the k^{th} catch for the net i, to be distinctive from N_{ik}, the number of shrimp of k^{th} length and i^{th} net in equation 3.

$N_{i\cdot}$ is the total catch by the net i.

P_{ij} can be estimated by the proportion of shrimp of length j from the total catch by the net i, $N_{ij}/N_{i\cdot}$. It follows that $T_{i\cdot} \cdot P_{ij}$ can be estimated by N_{ij}, $T_{c\cdot} \cdot P_{cj}$ by N_{cj} and γ_{ij} from equation (1) by

$$\gamma_{ij}^{*} = \frac{N_{i\cdot}\dfrac{N_{ij}}{N_{i\cdot}}}{N_{c\cdot}\dfrac{N_{cj}}{N_{c\cdot}}} = \frac{N_{ij}}{N_{cj}} \tag{3}$$

where N_{ij} is the total number of shrimp of length j caught by test net i and N_{cj} is the total number of shrimp of length j caught by the control net c.

Since it was difficult to measure all shrimp in the catch, although it had been done in flatfish and roundfish experiments (Davis 1934; Best 1961), a sample was taken from each tow. The sample proportion ($\hat{P}_{ij}$) calculated from the pooled sample can be used to estimate P_{ij}:

$$\hat{P}_{ij} = \frac{n_{ij}}{n_i} \tag{4}$$

where n_i is the number of shrimp in the pooled sample from net i and n_{ij} is the number of shrimp of length j in the pooled sample from net i.

Assuming that for a sample of size n, the number of all sizes (n_{ij}) follows a multinomial distribution with parameters n_i, P_{ij}, $\sum_j P_{ij} = 1$, then the sample proportion $\hat{P}_{ij}$ is the maximum likelihood estimators (MLE) of P_{ij}. With the total catch of net i ($N_{i\cdot}$) and net c ($N_{c\cdot}$) and the sample proportion ($\hat{P}_{ij}$, $\hat{P}_{cj}$), we obtain the MLE of γ_{ij} through γ_{ij}^{*} as

$$\hat{\gamma}_{ij} = \frac{N_{i\cdot}}{N_{c\cdot}} \frac{\hat{P}_{ij}}{\hat{P}_{cj}} = \hat{q}_i \hat{\theta}_{ij} \tag{5}$$

where $\hat{q}_i = \frac{N_{i\cdot}}{N_{c\cdot}}$

and $\hat{\theta}_{ij} = \frac{\hat{P}_{ij}}{\hat{P}_{cj}}$

This follows that if $\hat{\theta}_1, \cdots, \hat{\theta}_m$ are MLE of $\theta_1, \cdots, \theta_m$, and $W(\theta_1, \cdots, \theta_m)$ is a single valued function of $\theta_1, \cdots, \theta_m$, then $W(\hat{\theta}_1, \cdots, \hat{\theta}_m)$ is the MLE of $W(\theta_1, \cdots, \theta_m)$.
The sample catch ratio $\tilde{\gamma}_{ij}$ can be used to estimate γ_{ij}, where

$$\tilde{\gamma}_{ij} = \frac{n_{ij}}{n_{cj}} = \frac{n_i \hat{P}_{ij}}{n_c \hat{P}_{cj}} = \frac{n_i}{n_c} \frac{\hat{P}_{ij}}{\hat{P}_{cj}} = \frac{n_i}{n_c} \hat{\theta}_{ij} \tag{6}$$

In order for this estimate to be the MLE of γ_{ij}, equations (5) and (6) must be equal. This leads to the relation

$$\hat{q}_i \hat{\theta}_{ij} = \frac{n_i}{n_c} \hat{\theta}_{ij}$$

and implies that n_i/n_c must be equal to $\hat{q}_i$
where

$$\hat{q} = \frac{n_i}{n_c} = \frac{N_{i\cdot}}{N_{c\cdot}} \tag{7}$$

This means the ratio of sample sizes for the test net i and the control net c must be proportional to that of the total catches $N_{i\cdot}$ and $N_{c\cdot}$ or $\hat{q}_i$. When $N_{i\cdot}$ and $N_{c\cdot}$ are not known, then $N_{i\cdot}$ and $N_{c\cdot}$ are to be estimated by the sample statistics.

The sample sizes derived from equation (7) are like those from a proportional sampling scheme and will make $\tilde{\gamma}_{ij}$ in the maximum likelihood estimator of γ_{ij}, a preferred statistic in most inference problems. From equation (7), the original sampling scheme would be correct if the catches were similar for all nets. However, I know this was not true, especially for the larger meshes. More small shrimp escaped from the larger mesh and thus the total number of shrimp for each tow decreased (Walter Dahlstrom, Dept. Fish and Game, pers. commun.). Therefore some adjustments need to be made in order to obtain MLE of γ_{ij}.

From the 1956 shrimp data, the catch ratio of a test net and the control net could be calculated according to equation (5). $\hat{P}_{ij}$'s and $\hat{P}_{cj}$'s were obtained from combined length frequencies from all samples except those with no matches (Table 2). Total numbers of shrimp caught ($N_{i\cdot}$ and $N_{c\cdot}$) were estimated as

follows. The original data consisted only of the weight for each tow; count per pound was not recorded for every tow. I needed to estimate the total number of shrimp caught for each tow and sum them to obtain the total catch for any particular net. In order to estimate the total number of shrimp caught for each tow, I obtained the median length of shrimp from the existing sample. Its weight was estimated from a May 1968, Bodega Bay shrimp length-weight curve.

$$W = 9.34497 \cdot 10^{-4} \cdot L^{2.8811} \quad (8)$$

where

W was the predicted weight (g)

and

L was the shrimp carapace length (mm).

It was suggested (Pienaar and Ricker 1968) that when a sample length frequency is close to a normal distribution, the sample mean weight can be predicted by using sample mean length and the length–weight curve equation (8). The bias of the estimator is proportional to sample variance. This conversion is normally done for each age group separately. Because of the large amount of data collected in the 1956 survey, a simplified scheme was adopted to estimate the sample mean weight by using the sample median length. Let m be denoted the sample median length, w_m as the corresponding estimator for the sample mean weight through the W–L equation, and w as the true sample mean weight, then the bias of w_m is defined as

$$\beta = \mu_{w_m} - \mu_w$$

where μ_{w_m} is the population average of w_m

and μ_w is the population average of w.

Both 1956 data and 1973 market sampling data from Area B-2 were used to estimate β where sample mean weights or count per pound were available. w_m and w were calculated for each sample:

Let

$$v_i = w_{mi} - w_i, \; i = 1, \cdots, n,$$

then

$$\bar{v} = \frac{\Sigma v_i}{n}$$

is an unbiased estimator of β.

The 1956 data had 17 samples where counts per pound were recorded ($n = 17$), we obtained $\bar{v} = -0.06$ and $s_{\bar{v}} = 0.11$. Because of the large standard error of $\bar{v}$, the bias was not significantly different from zero. There were 48 samples from area B-2 in 1973 which were used for checking the bias ($n = 48$) which was $\bar{v} = 0.24$ with $s_{\bar{v}} = 0.06$. This indicated that sample median length through 1968 W–L curves overestimated the sample mean weight. This could have resulted from the skewness of the length frequency to the left so that the sample median length was larger than the average sample mean length. The skewness could be caused by the escapement of small shrimp. Since only the catch ratio was of interest, the bias of w_m may not have had any significant effect on the results. Thus w_m will be used later to estimate the count per pound of each tow.

Now for the k^{th} tow of the i^{th} net, let w_{ik} be the actual catch (in pounds) and z_{ik} be the estimated count per pound where $k = 1, \cdots, m_i$, and m_i is the total number of tows made for the i^{th} net; and let $\hat{N}_{i(k)}$ be the approximated number

of shrimp caught for the k^{th} tow and i^{th} net, then the total number of shrimp caught for the i^{th} net is

$$\hat{N}_{i\cdot} = \sum_{k=1}^{m_i} \hat{N}_{i(k)} = \sum_{k=1}^{m_i} W_{ik} Z_{ik} \qquad (9)$$

As to the control net, the total number of shrimp caught corresponding to the i^{th} net is

$$\hat{N}_{c\cdot} = \sum_{k=1}^{m_i} \hat{N}_{c(k)} = \sum_{k=1}^{m_i} W_{ck} Z_{ck} \qquad (10)$$

Using equations (9) and (10) we have

$$\tilde{q} = \frac{\hat{N}_{i\cdot}}{\hat{N}_{c\cdot}} = \frac{\sum_{k=1}^{m_i} \hat{N}_{i(k)}}{\sum_{k=1}^{m_i} \hat{N}_{c(k)}} \qquad (11)$$

where $\tilde{q}_i$, $\hat{N}_{iz}$ and $\hat{N}_{c\cdot}$ are the estimators of $\hat{q}_i$, $N_{i\cdot}$ and $N_{c\cdot}$ of equation (5).

The resulting $\tilde{q}_i$'s for the five larger net mesh sizes 1.43, 1.60, 1.62, 1.66 and 1.84 inches were 0.6, 0.16, 0.12, 0.065, and 0.035, respectively. Sample length frequencies and the $\tilde{q}_i$'s (Table 2) enabled me to estimate γ_{ij} according to equation (5).

RESULTS

The ultimate objective of this analysis was to determine differences in shrimp escapement from a series of trawls with varying mesh sizes. The catch ratio for each carapace length from 11 to 24 mm (4 to 11 inches) for the larger nets was calculated according to equation (5) (Table 3). The escapement rate of any net for a particular shrimp length is $1 - \hat{\gamma}_{ij}$.

If the differences of the catch ratios among the nets were only due to selectivity, then a symmetrical ogive with a lower asymptote of zero and an upper limit of unity would be expected. But the survey data (Table 3) showed that in some of the catch ratio comparisons there were ratios reaching a level greater than unity. As was pointed out in Beverton and Holt (1957), this could have been due to either sampling error or the differences of fishing efficiencies. I believe that a real difference in efficiency did exist because some of the commercial catch data indicated that larger mesh nets had higher total catch in weight than did smaller nets.

The relationship of the catch ratio and the shrimp carapace length for each of the nets was fit using a probit analysis technique since the scatter diagram showed that the data approximated a normal sigmoid curve. Probit analysis is the analysis of quantal response data using the probit transformation. It is used commonly in bio-assay experiments where different dosages of toxic substances are tested for the mortality rate which they produce (Sokal and Rohlf 1969). In the case of mesh experiments, the catch ratio is an index of the fishing mortality

TABLE 2. Sample Length Frequency (n_{ij} and n_{cj}) for the Five Large Nets and the Control Net.

Carapace length (mm)	*Mesh sizes (inches)*									
	0.69	*1.43*	*0.69*	*1.60*	*0.69*	*1.62*	*0.69*	*1.66*	*0.69*	*1.84*
11	6	3	2	0	7	0	9	0	0	0
12	46	16	38	0	39	1	51	0	21	0
13	159	40	135	0	106	2	139	0	65	0
14	214	80	225	4	138	1	240	2	85	1
15	95	61	135	13	93	5	122	1	59	1
16	32	22	35	13	21	1	27	0	13	1
17	110	130	86	56	104	19	121	25	71	9
18	192	308	160	209	227	61	253	83	138	30
19	92	257	133	258	155	108	137	103	68	38
20	38	101	44	113	67	71	50	104	33	62
21	55	178	59	211	77	222	84	307	61	156
22	44	158	38	162	59	264	47	410	44	161
23	14	40	10	51	19	122	17	158	15	101
24	1	3	2	4	3	18	1	22	2	13
25	0	2	0	0	1	1	1	0	0	1
Total (n_i)	1098	1399	1102	1094	1116	896	1299	1215	675	574
No. of samples (m_i)	11	11	10	10	11	11	13	13	7	7
$\tilde{q}_i$		0.6		0.16		0.12		0.065		0.035

TABLE 3. Catch ratio γ_{ij}.

Carapace length (mm)	*Mesh size (inches)* 1.43	1.60	1.62	1.66	1.84
11	.24	0	0	0	0
12	.16	0	0	0	0
13	.12	0	0	0	0
14	.16	0	0	0	0
15	.30	.02	.01	0	0
16	.32	.06	.01	0	0
17	.56	.10	.03	.01	.01
18	.76	.21	.04	.02	.01
19	1.32	.31	.10	.05	.02
20	1.25	.41	.16	.14	.08
21	1.69	.58	.43	.25	.11
22	1.35	.69	.67	.61	.15
23	1.41	.82	.96	.65	.28
24	–	.32	.90	1.53	.27

rate which increases with the length of the fish. Thus it seems suitable to apply probit analysis to estimate the catch ratio of any size of the shrimp when a particular mesh size is used (Table 4, Figure 3). For any given x, the corresponding probit value y will enable us to calculate the probability of Y less than y; $P(Y < y)$. This probability is then used as the predicted catch ratio for that carapace length x (Figure 4). The estimation of the catch ratio of any carapace length for any one of five nets is illustrated as follows. For the 1.43-inch net the expected catch ratio for the shrimp of length 17.4 mm (0.6 inches) (this includes the shrimp size x; $17.0 \leq x \leq 17.8$) is 0.56:

$$y_{17.4} = -0.7426 + 0.3404\ (17.4) = 5.18$$
$$p\{Y < 5.18 \mid Y \sim N(5,1)\} = 0.56$$

TABLE 4. Probit Regression Lines and the 50% Selection Length of Five Mesh Sizes.

Mesh size (inches)	*Probit regression lines*	*50% selection length (mm)*
1.43	$y = -0.7426 + 0.3404x$	16.87
1.60	$y = -2.7186 + 0.37x$	20.87
1.62	$y = -5.8 + 0.498x$	21.67
1.66	$y = -6.055 + 0.49179x$	22.47
1.84	$y = -3.8015 + 0.3517x$	25.03

y = the probit value which is the normal deviate plus five
x = carapace length (mm)

The 50% selection length is the x value corresponding to y equal to five (Table 4). A simple linear regression line was fit to the 50% selection length and the corresponding mesh sizes (Figure 5). It was found to be

$$y = 21.38 + 19.93(x - 1.63) \qquad (12)$$

where y : the 50% selection length (mm)
and x : the mesh size (inches).

The predicted 50% selection lengths for the mesh sizes 1.37, 1.43, 1.50, and 1.60

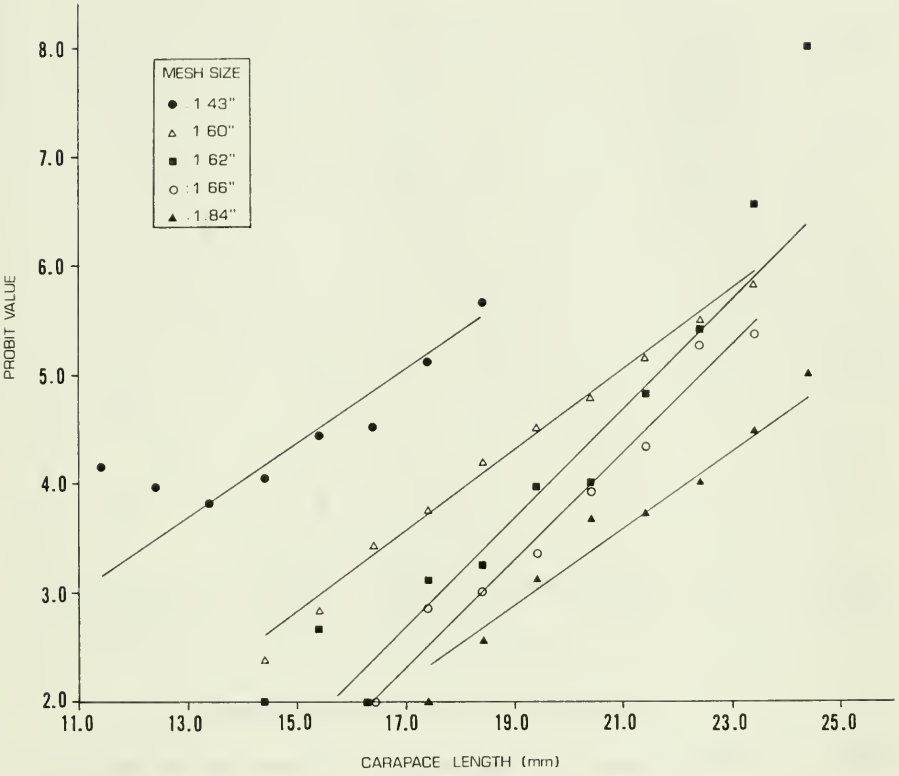

FIGURE 3. Probit regression lines for estimation of catch ratio.

inches are 16.20, 17.39, 18.79, and 20.78 mm (Table 5). With 50% selection lengths for various mesh sizes and a length frequency of shrimp available to the net, it is possible to estimate the percentage of the shrimp that is smaller than 50% selection length when a certain mesh size is used. The length frequency of any age group can be fitted to a normal distribution. The length frequency of 1-year-old shrimp in 1956 was compared with a normal distribution. Using chi-square technique, the difference detween the two distributions was not significant at 5% level (Table 6). Thus for 1- or 2-year-olds the expected length frequency can be calculated from the sample means and sample standard deviations ($\bar{x}$ and s). This is illustrated by using 1968 Area B-2 data. The carapace length of 1-year-olds averaged from 16 to 17.8 mm (0.6 to 0.7 inches) while the mean length of 2-year-olds increased from 20.35 to 21.64 mm (0.8 to 0.9 inches) through the season. The standard deviations varied little (Table 7). The percentage of shrimp smaller than 50% selection length by a particular mesh size was estimated for any age group using the normal approximation. For example, if 1.50-inch mesh was used, all the 1-year-olds with $\bar{x} = 16$ mm and $s = 0.76$ mm would have a higher than 50% escapement rate. As the season progressed, 85% of 1-year-olds with $\bar{x} = 17.8$ mm and $s = 0.94$ mm were smaller than 50% selection length. Since 2-year-olds were much larger than 1-year-olds during the month of May, only 5% of 2-year-olds had more than a 50% escapement rate (Table 8, Figures 6 and 7).

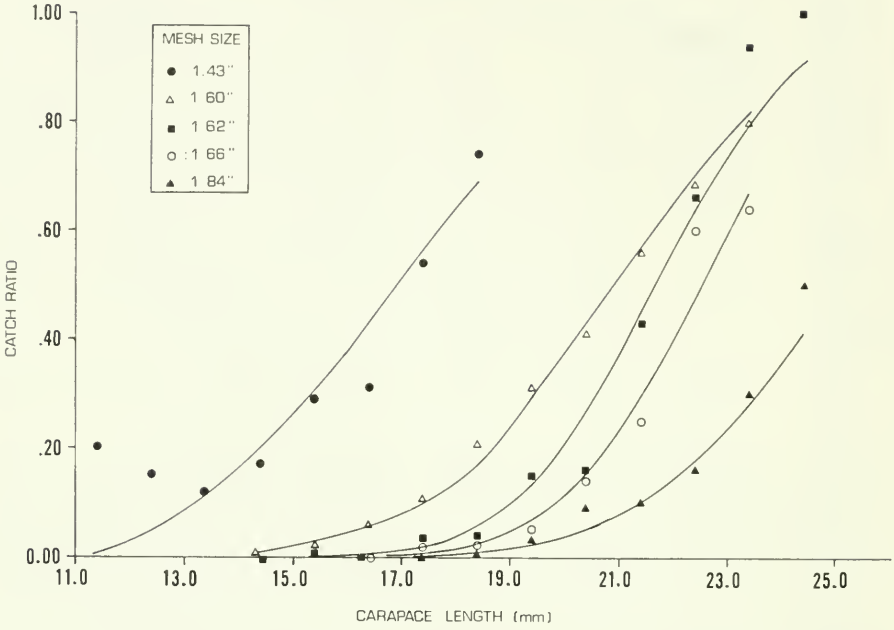

FIGURE 4. Probit catch ratio estimated from probit regression.

TABLE 5. 50% Selection Lengths, St. Errors, and 95% C.I. Derived from the Least Squares Regression Line.

Mesh size (inches)	*50% selection length (mm)*	*St. error (mm)*	*95% C.I. (mm)*
1.37	16.20	.59	16.2 ± 1.65
1.43	17.39	.49	17.39 ± 1.36
1.50	18.79	.38	18.79 ± 1.05
1.60	20.78	.27	20.78 ± .75

TABLE 6. 1956 April–June 1-year-old Length Frequency Fitted to Normal Distribution

Carapace length (mm)	*Observed frequency*	*Expected frequency*	$\frac{(E-O)^2}{E}$
11	8	5.51	1.125
12	84	71.63	2.136
13	294	286.52	0.195
14	439	440.8	0.007
15	230	242.44	0.63
16	47	55.1	1.19
TOTAL	1102	1102	$5.28 < \chi^2_3 = 7.81$

Because of the short life span of California ocean shrimp, the high natural mortality rate of 1-year-olds, and the wastage during processing (Dahlstrom 1972), it seems reasonable to protect the 1-year-olds so that the fishery can be carried on during the next season. Before any definite spawning ecruitment relationship is found, one criterion of regulating the mesh size wo d be based upon the escapement rate for the 1-year-olds. What I suggest is an average

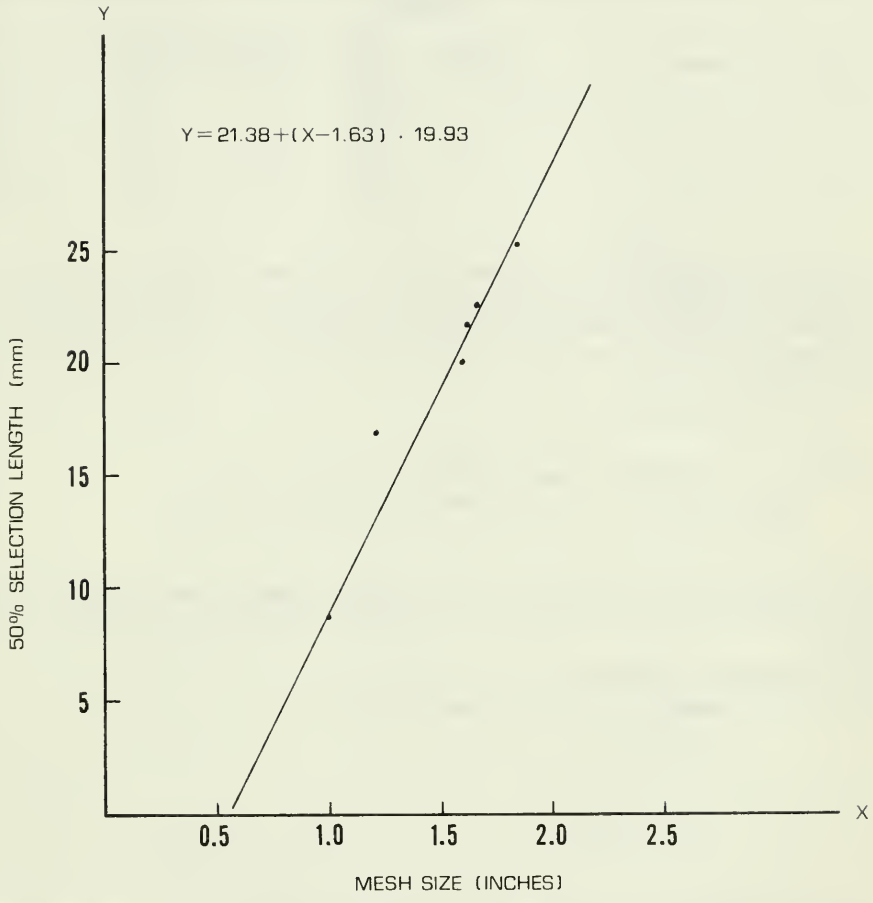

FIGURE 5. Linear relationship of 50% selection length and mesh sizes.

TABLE 7. AER's for 1968 and 1974 Area B-2 Shrimp Samples.

Year	*Month*	*Age*	*Carapace length (mm)*		*AER (inches)*		
			$\bar{x}$	*s*	*1.43*	*1.60*	*1.62*
1968	5	1	16.	0.76	0.68	0.96	0.99
	7	1	17.1	0.81	0.53	0.91	0.98
	9	1	17.83	0.94	0.34	0.85	0.96
	5	2	20.4	0.96	–0.3	0.59	0.79
	7	2	21.2	0.92	–0.43	0.48	0.65
	9	2	21.6	0.88	–0.51	0.43	0.57
1974	4	1	14.32	0.99	0.81	0.99	0.99
	9	1	18.04	0.94	0.28	0.83	0.96
	10	1	17.04	1.3	0.48	0.89	0.97
	4	2	19.76	1.16	–0.18	0.65	0.84
	9	2	21.11	0.53	–0.42	0.49	0.67
	10	2	21.65	0.53	–0.53	0.42	0.54

TABLE 8. Percentage of Shrimp with Escapement Rates of More Than 50% for 1968 Area B-2 Data.

Month	Age (years)	Mesh size (inches) 1.37	1.43	1.50	1.60
May	1	0.60	0.96	1.00	1.00
	2	0	0	0.05	0.68
July	1	0.16	0.69	0.99	1.0
	2	0	0	0	0.33
Sept.	1	0.05	0.32	0.85	1.00
	2	0	0	0	0.17

escapement rate (AER) for one age group for various mesh sizes. Since the growth rate of shrimp varies among seasons and among locations, the AER's of various mesh sizes can be used to determine the effect of those mesh sizes on the fishery if the length relative frequency (LRF) of any age group is known. The AER is defined as,

$$S_{i \cdot k} = \sum_j h_{cjk}(1 - \gamma_{ij}) \qquad (13)$$

where $S_{i \cdot k}$ is the AER for age k when mesh size i is used
h_{cjk} is the LRF by a control net of the length j of age k
$\sum_j h_{cjk} = 1$,
and the subscript j is summed over the carapace length of age k. Thus, $S_{i \cdot k}$ is the weighted average escapement rates for age k where the weights are the LRF's.

The derivation of equation (13) is as follows:
I have the average catch ratio for age k by mesh i as

$$\gamma_{i \cdot k} = \frac{\mu_{i \cdot} \sum_j P_{ijk}}{\mu_{c \cdot} \sum_j P_{cjk}} \qquad (14)$$

Applying the relationship given in equation (1) to equation (14) and assuming γ_{ij} is the same for all age groups, i.e. $\gamma_{ij} = \gamma_{ijk}$, I have

$$\gamma_{i \cdot k} = \frac{\sum_j P_{cjk} \quad \gamma_{ij}}{\sum_j P_{cjk}} = \sum h_{cjk} \quad \gamma_{ij} \qquad (15)$$

where $h_{cjk} = \dfrac{P_{cjk}}{\sum_j P_{cjk}}$

$$\sum_j h_{cjk} = 1$$

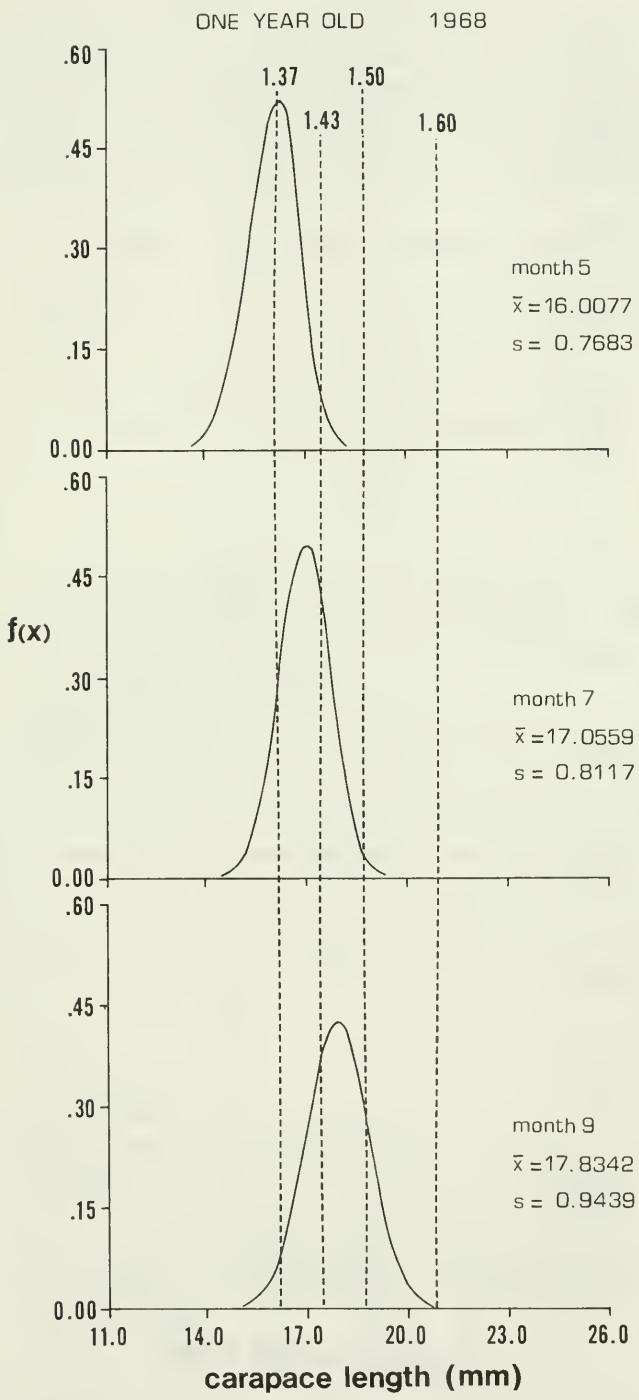

FIGURE 6. LRF of 1968 1-year-old approximated by normal distribution and 50% selection length for four mesh sizes.

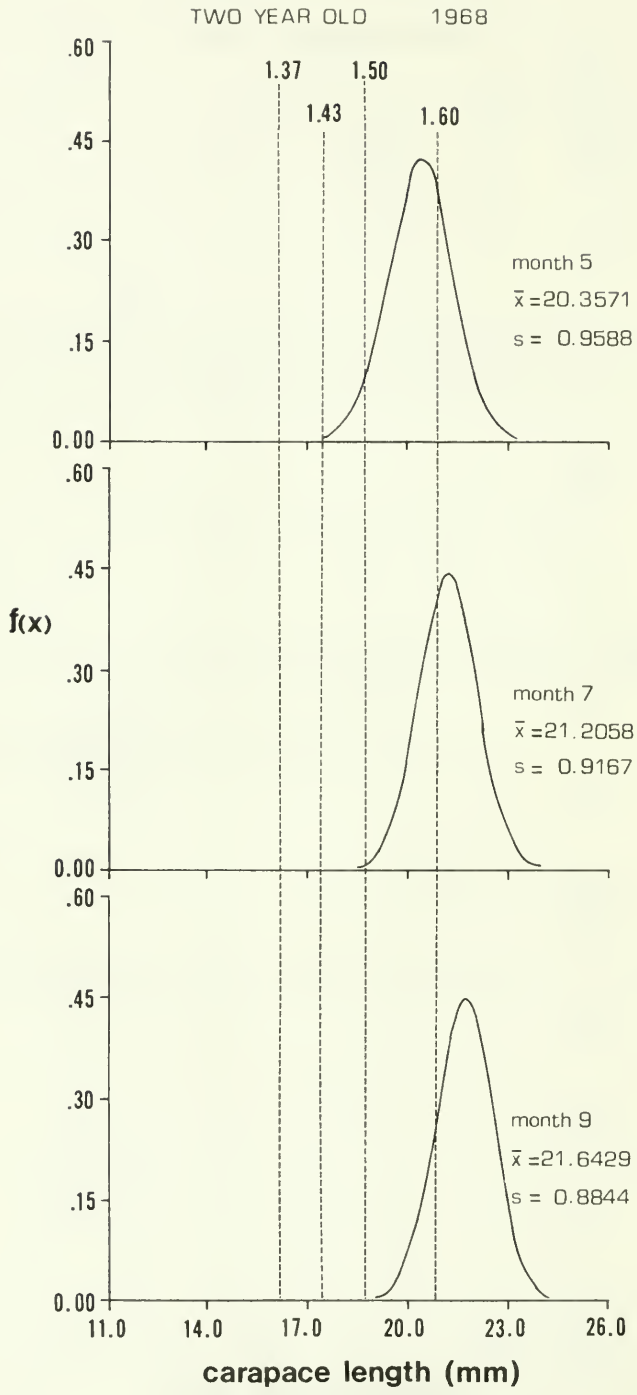

FIGURE 7. LRF of 1968 2-year-olds approximated by normal distribution and 50% selection length for four mesh sizes.

and the subscript j is again summed over the age k.

$S_{i \cdot k} = 1 - \gamma_{i \cdot k}$, thus equation (13) is obtained. AER is determined by γ_{ij} and h_{cij}. γ_{ij}'s are given in Table 3 and h_{cjk}'s are approximated by a normal distribution. In order to estimate the AER's for the various mesh sizes, 1968 and 1974 Bodega Bay shrimp data were used to provide 12 age groups with distinctive LRF's. The AER's for the meshes 1.43, 1.60, and 1.62 inches are calculated for each of the 12 age groups (Table 7).

TABLE 9. AER's with 95% Confidence Intervals

	Mesh size (inches)		
Length (mm)	*1.37*	*1.50*	*1.55*
14	0.44 ± 0.19	0.91 ± 0.15	1.08 ± 0.14
15	0.33 ± 0.17	0.80 ± 0.12	0.97 ± 0.12
16	0.23 ± 0.16	0.69 ± 0.10	0.86 ± 0.09
17	0.12 ± 0.15	0.58 ± 0.08	0.75 ± 0.06
18	0.01 ± 0.15	0.47 ± 0.07	0.64 ± 0.06
19	−0.10 ± 0.15	0.36 ± 0.07	0.53 ± 0.06
20	−0.21 ± 0.15	0.25 ± 0.07	0.42 ± 0.06
21	−0.21 ± 0.15	0.14 ± 0.09	0.32 ± 0.08

AER is the function of the mesh size and LRF which is generated by $\bar{x}$ and s (Table 7). Table 7 was constructed under the assumption that γ_{ij} is independent of the age, time, and location. Therefore, for two different age groups with $\bar{x}$ and s, the AER's are the same, whereas for two groups of the same age yet different $\bar{x}$, and(or) s, the AER will be different.

The current issue with respect to the shrimp fishery is whether or not 1.50 inches is the proper legal mesh size. The best way to answer this question would be to conduct experiments where a control net is towed side by side with commercial nets of differing mesh sizes (1.30 to 1.60 inches) so that the escapement rates of 1.50-inch net can be directly estimated from the catch data. Lacking this, data in Table 7 were used to derive estimated AER's for nets with mesh sizes not included in the 1956 experiments. A multiple regression line was fitted to the data where the AER's are regressed upon the mesh size, mean length, and standard deviation. The backward stepwise multiple regression line includes both mesh size and mean length, but not the standard deviation. The fitted line is

$$y = -2.89 + 3.55\, x_1 - 0.11\, x_2 \qquad (16)$$

where y : AER

x_1 : mesh size

x_2 : mean length of an age group

and the multiple correlation coefficient squared (R^2) is 0.83.

Equation (16) then is used to estimate the AER of nets 1.37, 1.50, and 1.55 inches for any age group of certain average length. For example, if mesh size 1.50 inches (x_1) is used and the mean length of shrimp of 1-year-olds is 16 mm (x_2), the estimated AER (y) is 0.69 with 95% C.I. (0.59, 0.79). Table 9 gives the estimated AER for the three nets applied to average lengths ranging from 14 to 21 mm (0.6 to 0.8 inches).

In order to find the effects of net 1.50 or 1.37 inches on California ocean shrimp, it is necessary to know the average carapace length of 1- and 2-year-olds

through the season. Since Area A has the largest shrimp bed, I used data from this area. For the 1-year-olds, the median average carapace length increased from 12.8 to 16.3 mm (0.5 to 0.6 inches) through the season (1969–1974) (Nelson and Dahlstrom 1975). The median carapace length was taken for each month across the years. Based on the median carapace length, nets with a mesh size of 1.37 inches will, on the average, catch 65% of the 1-year-olds in May and catch 77% of the 1-year-olds in September. A 1.50-inch mesh net will catch 16% of 1-year-olds in May and 31% of 1-year-olds in September. A 1.55-inch mesh size will catch at most 6% of 1-year-olds in May and 14% of 1-year-olds in September. But the 2-year-olds (18.7 to 21.0 mm) will have a 65% AER in May and 32% in September. This large AER for 2-year-olds is a loss to the fishery and should be prevented (Tables 9 and 10).

TABLE 10. Median Length of 1- and 2-Year-Old Shrimp in the Eureka Area, 1969–1974.

	Age (years)	
Month	*1*	*2*
April	12.8	18.7
May	14.47	20.
June	14.53	20.
July	15.25	20.5
August	15.76	20.8
September	16.33	21.
October	16.3	21.6

As far as AER's are concerned, 1.50-inch mesh seems to be a reasonable choice. It insures good escapement of 1-year-olds through the season and at the same time will allow harvest of most of the 2-year-olds (Table 9). Commercial fishermen often argue that large mesh nets cause the efficiency to decrease as the mesh size increases. Therefore, the efficiency of various mesh sizes should be taken into consideration when making the final decision as to an appropriate minimum mesh size for the shrimp fishery.

Catch per hour (CPH) has been used as an index of fishing efficiency. But the difficulty of making inferences directly from commercial catch data is that fishing time, boat size, fisherman's know-how, and the location of fish are all variables. Thus, the differences in CPH can be due to either the mesh sizes and(or) the other variables. Since there have been no experiments conducted to check the CPH of nets with different mesh sizes as the only variable, we chose the CPH of four otter trawls with different mesh sizes fished by Bodega Bay vessels from June through August 1975. In this case fisherman's know-how and boat size were the variables. Time and location were the same since all four boats fished during the same 3 months and the Bodega Bay shrimp bed (Area B-2) is rather small and distribution of shrimp is fairly uniform (Walter Dahlstrom, pers. commun.). Because larger mesh nets tend to have longer headropes, the CPH is further divided by the length of headrope. Thus the statistics used are CPH per foot (CHF). Since there is more homogeneity of fishing conditions within a given day than between days and the lack of knowledge of the underlying distribution of CHF, a nonparametric multiple comparison was used in analyzing the data (Bradley 1968) (Table 11).

TABLE 11. CHF's of Four Mesh Sizes Used in Bodega Bay, 1975.

Month	Fishing day	Mesh size (inches) 1.44	1.50	1.51	1.54
June	1			47.83	66.46
	2	27.77	22.77	34.93	59.40
	3	15.85	27.64	26.72	47.74
	4	26.86	–	24.91	42.18
	5	42.11	37.52	37.41	40.44
	6	22.26	17.16	18.60	22.38
	7	5.41	2.26	8.75	9.26
	8	–	–	24.62	28.40
	9	39.61	33.89	28.22	42.06
	10	44.44	27.09	39.07	31.51
July	1	53.65	42.72	71.10	76.86
	2	22.95	13.03	77.28	126.61
	3	–	–	105.36	115.40
	4	83.03	71.35	70.71	63.97
	5	11.73	7.96	8.10	19.59
	6	22.47	24.77	24.32	40.00
August	1	25.79	34.72	–	–
	2	19.65	22.40	26.18	30.11
	3	–	–	9.92	16.47
	4	16.37	17.40	16.25	15.86
	5	–	–	0	–
	6	–	–	0	–
	7	0.47	0	0	–
	8	46.02	–	–	–
	9	66.50	74.57	–	188.43
	10	48.63	37.34	–	43.67
	11	26.00	50.11	–	63.75
	12	30.25	46.18	–	50.76

The data in Table 11 are further condensed by taking the average of the entries within each fishing day across the months (Bradley 1968) (Table 12).

TABLE 12. Mean CHF's of Four Mesh Sizes Used in Bodega Bay, 1975.

Fishing day	Mesh sizes (inches) 1.44	1.50	1.51	1.54
1	39.72	38.72	59.47	71.66
2	23.46	19.40	46.13	72.07
3	15.85	27.64	47.33	59.87
4	42.09	44.38	37.29	40.67
5	26.92	22.74	15.17	30.02
6	22.37	20.97	14.31	31.19
7	2.94	1.13	4.38	9.26
8	46.02	–	24.62	28.40
9	52.84	54.23	38.22	115.25
10	46.54	32.22	39.07	37.59
11	26.00	50.11	–	63.75
12	30.25	46.18	–	50.76

For the final analysis, data for fishing days 8, 11 and 12 were eliminated

because of incomplete entries. The CHF's within each fishing day were ranked (Table 13) and the Friedman test (Bradley 1968) was applied. I then have

$$\chi_r^2 = \frac{12}{mc(c+1)} \sum_{i=1}^{c} \left(\sum_{j}^{m} R_{ji} - \frac{m(c+1)}{2} \right)^2$$

$$= \frac{12}{mc(c+1)} \sum_{i=1}^{c} \left(\sum_{j-1}^{m} R_{ji} \right)^2 - 3\,m(c+1)$$

$$= \frac{12}{9 \cdot 4 \cdot 5}\, 2158 - 3 \cdot 9 \cdot 5$$

$$= 8.87$$

where R_{ji} is the entry in j^{th}row and the i^{th} column
m : number of fishing days
c : number of mesh sizes.
X^2, under H_o of no different CHF's among the four nets, follows X^2 distribution with (c-1) degrees of freedom.

TABLE 13. Ranks of the Four Mesh Sizes Used in Bodega Bay, 1975.

Fishing day	*Mesh sizes (inches)*			
	1.44	*1.50*	*1.51*	*1.54*
1	2	1	3	4
2	2	1	3	4
3	1	2	3	4
4	3	4	1	2
5	3	2	1	4
6	3	2	1	4
7	2	1	3	4
8	2	3	1	4
9	4	1	3	2
TOTAL	22	17	19	32

Since $X^2, = 8.87 > X^2_3 = 7.81$, I concluded that there is a difference of CHF's among the mesh sizes. From Table 12, it is apparent that the 1.54 inch mesh net ranks consistently higher than the other three meshes. This indicates that the larger mesh net will not result necessarily in decreased fishing efficiency. If the fisherman is competent, and the net is handled correctly, mesh size, within limits, may not have a major effect on the fishing efficiency. In addition, there does not seem to have been significant CHF differences among the three small nets in my analysis. The possibility of decreasing efficiency as the mesh size increases seems to be questionable within the range of mesh sizes with which I dealt.

DISCUSSION

The beam trawl net with 1.50-inch mesh size would allow an escapement rate for 1-year-olds of 91% in April to 58% in September (Table 9). Since the original

survey in 1956, the shrimp fleet has changed from beam trawls to otter trawls. The difference between the escapement rates of these two kinds of nets is probably slight (Davis 1934).

I recommend that experiments be conducted to determine the escapement rates of the otter trawls. Thus, the results of 1956 experiments can be directly or indirectly applied to the otter trawls used in the present shrimp fishery.

The 1975 data from Bodega Bay comparing the four commercial otter trawl mesh sizes indicate that the small meshes do not have necessarily higher catch per effort than large mesh nets. On the contrary, the largest net (1.54 inches) had the highest CHF for several seasons. This high catch can be due to a combination of factors; large and powerful vessel, competence of the fishermen, net construction, and mesh size. The estimated escapement rates of the 1.50 inch mesh net and the comparison of fishing efficiency lead me to support the adoption of 1.50 inches as the legal minimum mesh size.

ACKNOWLEDGMENTS

The author wishes to thank her colleagues at the Department of Fish and Game for reviewing the manuscript and providing editorial assistance.

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MIGRATION OF AMERICAN COOTS WINTERING IN NORTHWESTERN CALIFORNIA

American coots (*Fulica americana*) in northwestern California are common winter visitants and migrants and uncommon in the summer months. A few broods have been recorded from Del Norte County and Humboldt County (Yocom and Harris 1975).

In the spring of 1954, 209 American coots were banded in the area of Arcata, California, known as the Arcata "Bottoms." The purpose of the banding was to find out where the birds migrated once they left the wintering areas along the coast and along what routes of migration they traveled. Recoveries from hunters were the source of most of our data on the banded birds. The banding was done under the supervision of C. F. Yocom. Twenty-three of these 209 coots were recovered during the fall–winter 1954–55 waterfowl hunting season either as a result of hunting, trapping, or other mortality factors. All of these 23 coots were recovered within 900 m (1000 yards) of the banding site. This seems to be significant in that these coots apparently returned from their northern breeding grounds to the exact area that they had occupied the preceding winter.

From banding recoveries, it is evident that some of the wintering American coots from the Lake Earl area, Del Norte County, south to the Eel River, Humboldt County, in northwestern California, breed as far away as the marshes of British Columbia and on across the Rocky Mountains to at least the prairie potholes of Alberta, Canada (Figure 1).

The recovery records of American coots banded in northwestern California were similar to many recoveries of wigeons (*Anas americana*), and mallards (*Anas platyrhynchos*) that had been banded in Humboldt County and recovered in Oregon, Washington, and British Columbia (Yocom and Denson 1962).

California Department of Fish and Game recovery records of coots banded at Tule Lake, Siskiyou County, California, prior to the waterfowl hunting season, and recovered during the hunting season in Humboldt and Del Norte counties indicate that there are coots that migrate in an east-west direction across northern California. The route would be from Tule Lake across the Cascade, Klamath and North Coast ranges to the northwestern California coastal areas. Also, coots banded in winter in California at Gray Lodge, Sutter County, and Grizzly Island, Solano County, have been shot in the northwestern coastal areas of California (Figure 2).

Apparently, mountains are no barrier for migrating American coots.

Migrations of coots have not been recorded because they move at night; however, we have some information that may represent typical activity of coots as they start migratory flights. William Henry, graduate student in Wildlife Management at Humboldt State University, observed what he considered the start of northward migration on April 18, 1976, at 7:55 p.m. Henry's observations were made at the South Spit of Humboldt Bay, Humboldt County, California. He stated the following: "Large concentrations, 300–400 coots in close proximity to each other and exhibiting what appeared to be nervous behavior, gathered along the sandspits. Single coots took flight and headed into the wind, which was out

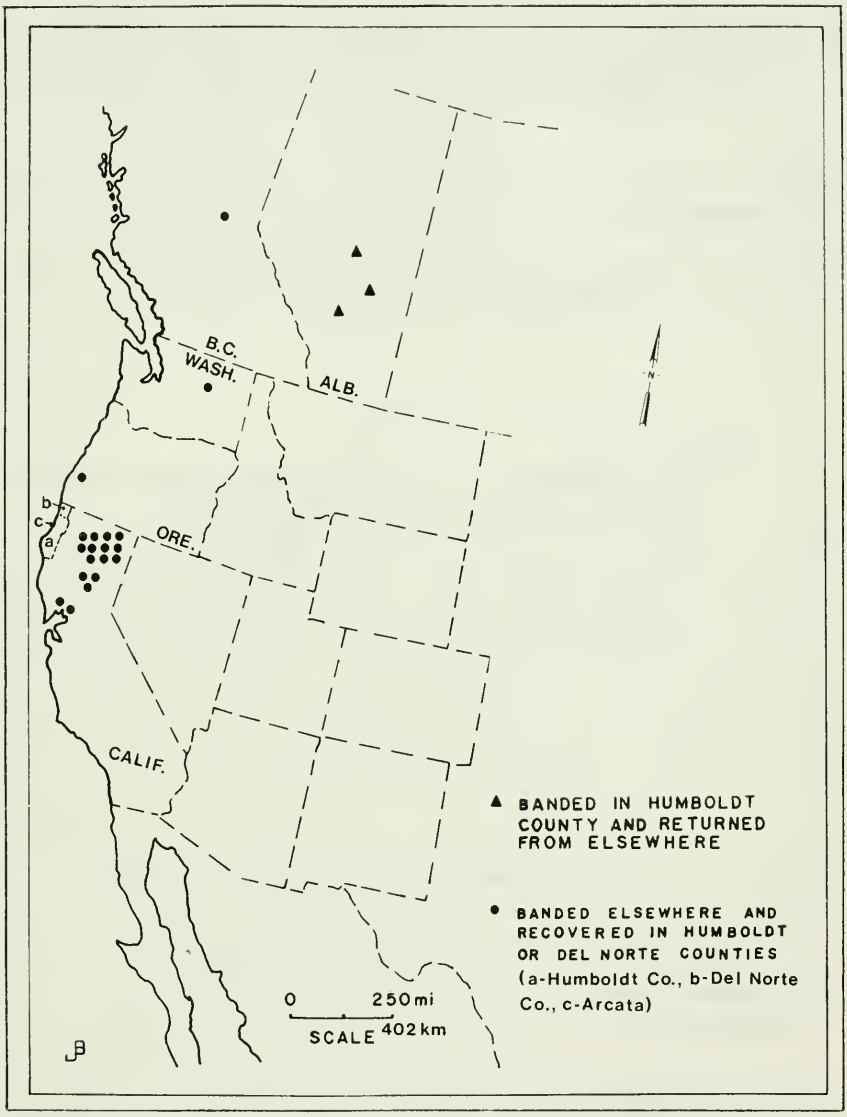

Figure 1. Recovery locations of American coots banded near Arcata, Humboldt County, California, or banded elsewhere and recovered in Humboldt or Del Norte counties, northwest California.

of the northwest at a velocity of 10–25 miles (16–40 km) per hour. The birds rose to about 150 feet (50 m) in height and turned to the northeast still gaining altitude. Many coots circled to higher altitudes before heading off to the northeast." He noted that the coots flew off as scattered single birds rather than in flocks.

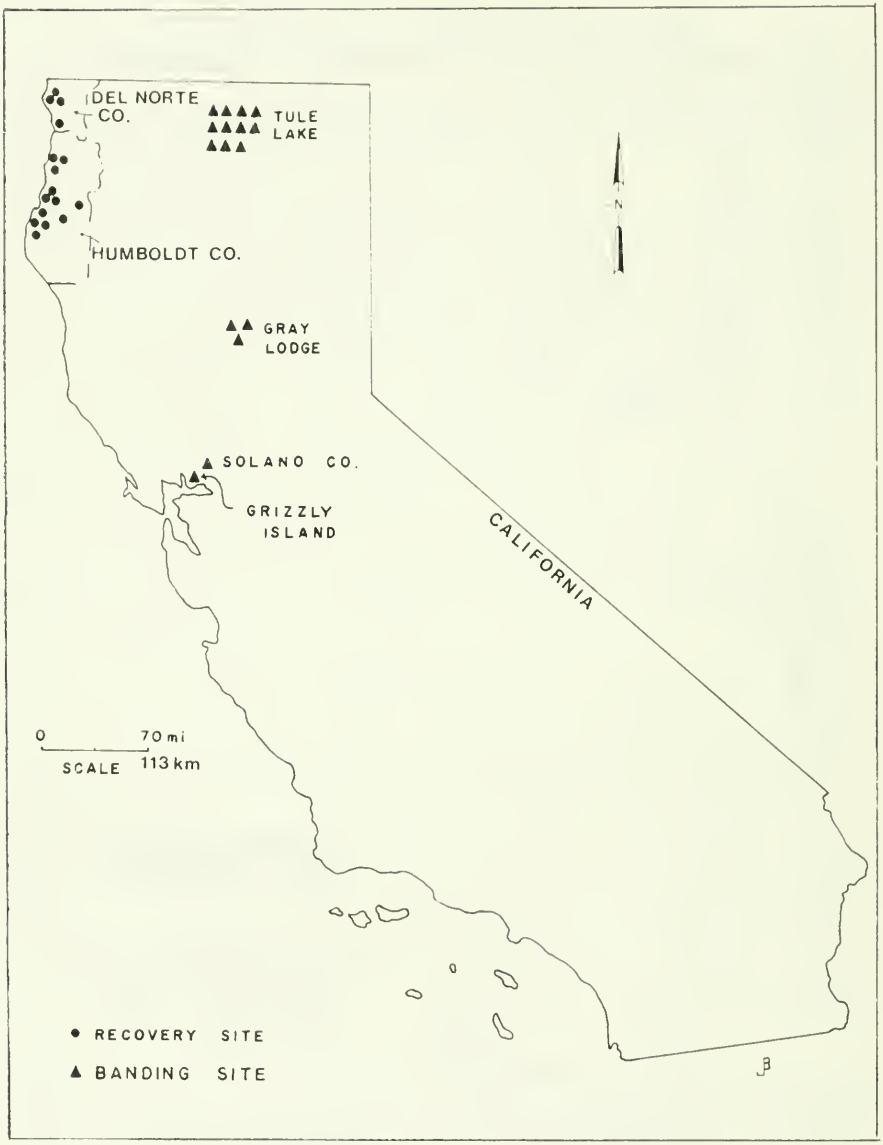

Figure 2. American coots recovered in Humboldt and Del Norte counties, northwest California, that were banded at either Tule Lake, Siskiyou County, Gray Lodge, Sutter County, or Grizzly Island, Solano County, California.

On February 20, 1977, at about sundown and with the fog moving in, Yocom noted eight tight groups of American coots in the water near the U.S. Highway 101 area of Freshwater Lagoon, Humboldt County. There were about 100 birds in each compact group, and individuals were moving about quickly in what appeared to be a nervous manner. This action may have preceded northward migration that may have occurred later that evening or night.

ACKNOWLEDGMENTS

We wish to thank Frank Kozlik and Warren Rienecker, California Department of Fish and Game, for sending banding recoveries of coots from northwestern California, and Fred Kindel and Dale Horn, former Wildlife students at Humboldt State University, for banding American coots on the Arcata Bottoms.

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A DIVER-OPERATED NET FOR CATCHING LARGE NUMBERS OF JUVENILE MARINE FISHES

As an integral part of the Department of Fish and Game's ongoing research into central California marine sportfish, we investigated various aspects of the population biology of juvenile fishes associated with kelp, *Macrocystis* sp, and the kelp canopy. During most months many juvenile fishes can be found closely associated with kelp. However, prior attempts to collect these fishes with assorted types of equipment were largely unsuccessful. A device capable of easily capturing large numbers of juvenile fishes within the kelp forest, as well as beneath the kelp canopy, was needed for our proposed mark and recapture study. We felt that a non-gilling net operated by two scuba divers might work satisfactorily.

Netting catalogues were consulted for information on available twine material, mesh size and style, and net sizes. We selected a 3.7 by 3.7-m (12 by 12-ft) "drop net" constructed with 18-lb test nylon. To avoid gilling fish and to create less drag in the water, we chose 6-mm (¼-inch) mesh, regular knit style.

The net was dyed using two packages of dark red Rit dye. After drying, four 38-mm (1.5-inch) diameter wooden dowels 1-m (39-inches) long were tied along two sides of the net (Figure 1). These extensions enabled the divers to open the net fully and maneuver it more easily.

We operated the net in a variety of ways, fitting the capture method to the specific situation. Most frequently, the net was lifted beneath a school by divers on opposite sides of the net (Figure 1). When a school of fish was located, the net was deployed well below them, usually just above the bottom. The divers, equipped with buoyancy compensators, partially inflated these devices and began a rapid swimming ascent keeping the net open as far as possible. Thus, the net was brought up around the fish. After the school was captured in the bag of the net, the sides were brought together and rolled on the dowels to prevent the fish from escaping.

Two important points need to be mentioned. First, the divers must be careful to exhale while rapidly ascending to prevent an air embolism from occurring.

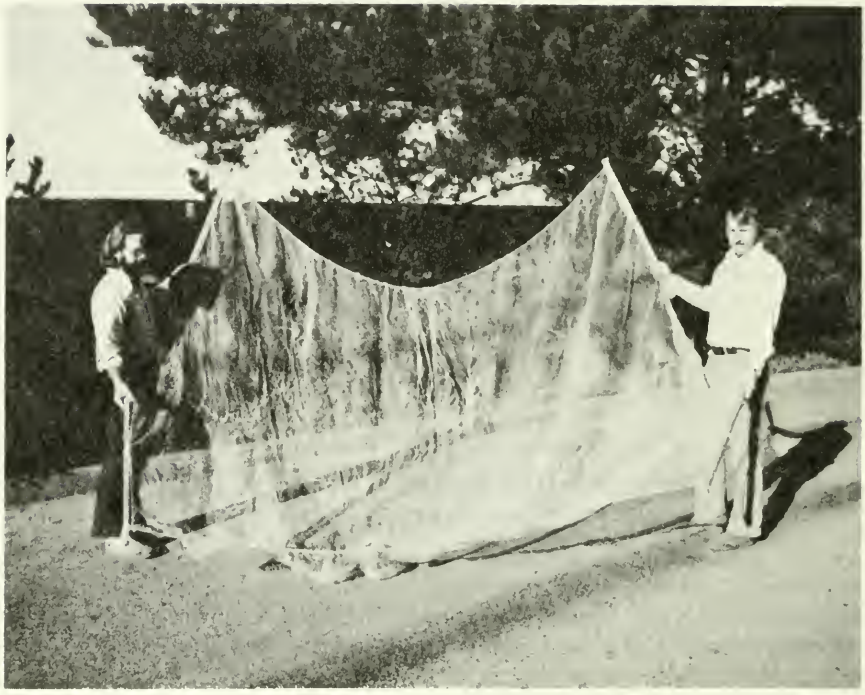

FIGURE 1. Net with dowels attached. *Photograph by Kim McCleneghan, November 1976.*

Second, attention must be given to the path of rising scuba exhaust bubbles while positioning the net under a fish school. Bubbles ascending through the school disperse the fish.

To capture fish which remained in or near kelp fronds, one side of the net was wrapped around the plant and the divers ascended with the net in this fashion. Fishes in the fronds were frightened into the net as it was lifted. Schools of fish hovering over drift algae on sand bottoms were caught using the net in a seine-like manner. Here a third diver was useful to herd the fish toward the approaching net.

After a "scoop", the net and captured fish were taken to the awaiting boat. There, an on-board assistant quickly removed the fish, placed them in holding tanks, and returned the net to the divers for another "scoop". Generally, the entire procedure took 5 to 10 min. This was difficult work for the divers, requiring much swimming and many descents and ascents. About 20 to 25 lifts could be made in a day by one team. Additional divers were useful to distribute the workload.

In terms of catch-per-unit-of-effort, the net was most successful when used to catch juvenile blue rockfish, *Sebastes mystinus;* juvenile kelp rockfish, *Sebastes atrovirens*; and kelp surfperch, *Brachyistius frenatus.* Juvenile blue rockfish were captured in open areas between kelp plants, juvenile kelp rockfish were caught by wrapping plants, and kelp perch were captured beneath the canopy. Also taken were four other species of juvenile rockfish, three species

of adult rockfish, and eleven other incidental fish species.

The efficiency with which the net captures fishes is affected by a number of factors including water depth, transparency, and wariness of fishes to the divers as well as the species of fish and size of the individuals. Small, ca. 65 mm (2.5 inches) total length (TL) juvenile blue rockfish form dense schools having many individuals which are more easily captured than the faster swimming larger juveniles, ca. 100 mm (4 inches) TL that form loose schools. On one occasion over 2,500 small juvenile blue rockfish were captured in a single "scoop". An average of 5,000 (range 2,700 to 9,100) fish were captured during each day of the 3-week study.

—*Kim McCleneghan and James L. Houk, Calif. Dept. of Fish and Game, Operations Research Branch, 2201 Garden Road, Monterey, California 93940.* *This work was performed as part of Dingell-Johnson project California F-25-R, "Central California Marine Sportfish Survey," supported by Federal Aid to Fish Restoration funds. Accepted for publication March 1978.*

SIGHTING OF A CALIFORNIA SEA LION, *ZALOPHUS CALIFORNIANUS CALIFORNIANUS,* IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

It is becoming evident that sea lions are using estuaries and rivers of the west coast of North America for purposes not yet understood. This paper further documents such use.

We are reporting the sighting of a pinniped, tentatively identified as a California sea lion, in the Sacramento-San Joaquin Estuary on 20 January 1976. The sighting was made between 1630 and 1700 hours on a sunny, calm afternoon. The sea lion was observed from a boat as close as 30 m (100 ft). Identification was based on several factors. Of the seven species of pinnipeds reported (Frey 1971; Daugherty 1972; Fed. Reg. 1975) from the California coast and adjacent islands, the two species observed most often are, according to Frey (1971), the California sea lion and Stellar sea lion, *Eumetopias jubatus.* The pinniped we report had a silhouette most closely matching that of *Zalophus californianus* as given by Daugherty (1972). The animal had a dark-brown head with a distinctive light-colored muzzle. The muzzle was longer and more pronounced than that of a Stellar sea lion, and it merged into a sharply sloped forehead.

This sighting is the second record of a California sea lion in the estuary since May 1973. The first, reported by Paulbitski (1974), was a juvenile California sea lion sighted and captured in the Mokelumne River near Thornton.

The sea lion reported here was swimming east near the shoreline across from the Pittsburg Marina (Lat 38°02'22" N, Long 121°52'50"W). It was followed by boat to the mouth of Middle Slough (Lat 38°01'50" N, Long 121°50'55"W). At no time did the sea lion seem disoriented, but continued to swim steadily eastward. We passed beyond it by several hundred meters and delayed in a small embayment. Minutes later it passed us as it headed on upstream.

We had measured some physical parameters of the water a few minutes before we first spotted the sea lion. The measurements were made about 1.6 km (1 mile) downstream, south of Chipps Island, midchannel, at a depth of 1 m (3.3

ft) with Martek temperature and salinity meters. We recorded a temperature of 9 C (48 F) and a salinity of $3^0/_{00}$. The tide was flooding to high high water. River discharges were not especially high because of low rainfall for the year.

The reason(s) that California sea lions enter the Sacramento-San Joaquin Estuary is (are) unknown. Adult and subadult male California sea lions migrate northward along the California coast in the fall and winter (Peterson and Bartholomew 1967; Braham 1974; Fed. Reg. 1975). Migration may increase the abundance of animals in the San Francisco area, but any association with movements into less saline water remains unexplained. Exploration for food or territory may be involved. Stellar sea lions, also for reasons unknown, travel 35 to 70 miles upstream from the sea in northern California rivers (Paulbitski 1974).

Hopefully, future accumulation of data on sea lions in west-coast estuaries and rivers will lead to understanding of their use of these waters.

ACKNOWLEDGMENTS

We wish to thank Dave Zeiner of the Marine Resources Branch, California Department of Fish and Game, for his assistance in searching the literature. Also, we thank Dan Varoujean of the University of California at Davis for his help with the identification.

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—Richard M. Sitts, Stephen P. Hayes, and Allen W. Knight, Hydrobiological Laboratory, Department of Land, Air and Water Resources, Water Science and Engineering Section, University of California, Davis, California 95616. *Accepted for publication June 1977.*

BOOK REVIEWS

Birds of the Yosemite Sierra—A Distributional Survey.

By David Gaines, Cal-Syl Press, 1494 MacArthur Blvd., Oakland, CA, 1977; xxviii + 153 p., illustrated. $6.75 paperback.

The value of this regional avifauna analysis became obvious even before I finished reading the introduction. Not one to miss the smallest detail, Gaines has compiled an extraordinary amount of information on the historical and present status of the birds of what he calls the Yosemite Sierra. The region covered includes the Sierran Crest from Mt. Lewis south to Mammoth Pass, the Ritter Range, Yosemite National Park, and a similar size area east of the crest from Bridgeport Valley south to Crowley Reservoir.

The introduction includes descriptions of 16 habitat types in the region with accompanying lists of birds associated with each. Also, there are sections on nomenclature, terminology, human impact, and bird watching.

The text consists of species accounts for the 285 birds observed in the Yosemite Sierra. Each account contains information on abundance, seasonal occurrence, altitudinal and regional distribution, habitats utilized, and nesting. Representative or probable breeding localities are given for species known or suspected to be nesting in the region. Historical comparisons are made and the effects of development, habitat modification and human activity are discussed. The accounts cover species that have been extirpated from the region (e.g., harlequin duck), those that are declining (e.g., willow flycatcher), and some that are increasing their distribution and numbers (e.g., brown-headed cowbird). One especially interesting section deals with field identification of the five similar species of *Empidonax* flycatchers of the region. Gaines provides many clues for easier identification of these confusing birds.

Data for this book have come from all known published sources and the personal journals of many bird watchers and ornithologists. The thoroughness of this survey was greatly enhanced by the contributions of these thoughtful note-takers.

The author points out many unanswered questions concerning migration, disjunct distribution, and breeding status. For example, nests of common merganser and hermit warbler have not been found in the region, although both are known to breed there.

Whether a professional ornithologist or an amateur bird watcher, you will find this book valuable. It is a must for anyone conducting avian research in the Yosemite Sierra, but its application is not restricted to this region. The information presented on seasonal and altitudinal distribution and habitat selection can be applied to similar areas outside the region. Hopefully, this book will stimulate the publication of analyses for other regions, thereby providing the framework with which our avian populations may be continually monitored.—*Robert Lee*

The Complete Fisherman's Catalog.

By Harmon Henkin; J. B. Lippincott Co., N.Y., 1975; x + 461 p., illustrated, $7.95.

Harmon Henkin's "The Complete Fisherman's Catalog" is just that—complete. It took me a hell'uva long time to review this book because it is so complete and is really fascinating reading. You can sit down and read it for hours or pick it up and glance through it for a few minutes. Basically, it is divided into three main sections: Fly Fishing Tackle; Tackle for Spinning, Baitcasting, Trolling, and Related Techniques; and Service and Accessories. Each subsection, for example the one on fly reels, starts with a brief paragraph on "what we looked for in quality" followed by an alphabetical listing and review/opinion of the top of the line products. No prices are given, which would date the catalog too quickly, but the book is profusely illustrated with pictures of the products, flies, fish, and old fishing prints. I have faith in the author's opinion and the products he lists because I've used them myself and, in the vast majority of the instances, agree with him. Interspersed among all the discussion of items of fishing tackle are notes on game fish, recipes, a short novel by the author, articles on tackle construction, repair or care, and how-to articles by the author or other well-known outdoor authors.

I can recommend this book not only for its information value but also for its entertainment value; well worth the $7.95.—*K. A. Hashagen, Jr.*

Fishwatchers' Guide To the Inshore Fishes of the Pacific Coast

By Daniel W. Gotshall; Sea Challengers, Monterey, California, 1977; 108 p. color plates; $8.95 soft cover

The Fishwatchers' Guide is a compact accurate guide identifying 93 commonly observed Pacific coast fish. The scope of the guide is limited to those species most commonly found in waters from 10 to 150 ft. The well known large game fish and the very small shallow water species are not included. Only those species that can be identified alive and in the water are included. Thus the guide is excellent for identifying fish observed while scuba diving.

Some natural history information and distinguishing physical characteristics or field marks are provided for each species. Full color photographs of living specimens in their natural habitat are also included for all but three species.

The author is a prize-winning underwater photographer. Most of the 95 color plates reflect this prize winning ability, especially the coverage of the rockfish family. There are, however, a few plates that do not depict the identified species well. The natural history information, the keys to family, and the generally excellent photographs make this guide a handy reference for the non-specialist as well as a nice supplement for the specialist.—*Fred Wendell*

Poissons de Nouvelle Caledonie et Nouvelles Hebrides

By Pierre Fourmanoir and Pierre Laboute. Editions du Pacifique, 6 rue Casimir Le Lavigne, 75006 Paris, France. 1976. 376 pp. $39.95.

More than 800 exquisite color photographs grace the pages of this beautiful volume. Obviously, it was intended for a place of honor on a coffee table or similar clearly-visible spot where a host or hostess could impress the afternoon or evening bridge-playing crowd, tea drinker, occasional visitor, or partygoer. This it will do admirably, but it also will serve as an excellent reference for identifying a myriad of fishes that inhabit the reefs and nearby waters of New Caledonia and New Hebrides.

The first 18 pages introduce very briefly some of the physical, social, and economic attributes of these tropical isles, and 21 carefully-selected photos supplement perfectly the short written accounts. This section is followed by chapters on fisheries, past and present, and a few remarks concerning fish anatomy, classification, taxonomy, vernaculars, and life styles.

The next 16 chapters (4 through 19) deal with various "natural" groups of fishes and/or fish families (e.g., serranids, lutjanids, labrids and parrotfishes, nocturnals, pomacentrids and anemonefishes, sharks and rays, etc.). Although not all genera or species are covered, and not all coverage is identical, one could certainly arrive at precise identification for a vast number of species inhabiting the waters of this area. The superb photos, most in natural habitat, are of such excellent quality that they alone would suffice in most instances.

The one drawback to the volume is the heavy, glossy paper on which it has been printed. While this is ideal for reproducing color photos, under no circumstances will it stand up to field usage or moisture of any type. In fact, the weight of the pages of an inscribed copy sent me from New Caledonia had caused them to tear loose from the binding while in transit. On the other hand, today's postal system is capable of destroying a metal book with a welded binding.

I am informed that this book is not for sale in the USA, so it must be purchased directly from the publisher as noted above.—*John E. Fitch*

New Techniques for Catching Bottomfish

By Doug Wilson and Fred Vander Werff; Gordon Soules Book Publishers, Vancouver, B.C. Canada, 1977; 150 p. $4.95.

This is a complete book on fishing for bottomfish, that myriad of species comprised mainly of rockfish (*Sebastes* sp). Bottomfish are largely overlooked by northeastern Pacific recreational anglers in favor of salmon; only in California, where rockfish is the leading species in numbers caught by marine anglers, are there well developed recreational fisheries.

The authors describe how to make lures, jigs, and terminal gear and they recommend rod, reel, and line combinations. They describe how to safely get to and from fishing spots, how to find fish, catch them, identify them, care for the catch, fillet fish, and finally cook the catch.

The new techniques include the use of plastic worms in various terminal arrangements. Other lures, jigs, and bait are also described for bottomfish along with fishing techniques for use from shore to 400 ft depths. The authors share techniques that less generous anglers would keep secret.

Doug Wilson's prize winning photographic skills are known to many. The photographs in this book

may not rank with Doug's best, but they add immeasurably to the text.

Editorial comments are that the copper rockfish on pages 13 and 30 look like quillback rockfish (*Sebastes maliger*), which they also have the specific name mispelled *malinger*. A caution to amateur Chinese chefs is that the recipe for steamed rockfish on page 106 calls for at least 4 times the soy sauce needed. The ginger root is best used to garnish the fish while steaming. Use ¼ cup of soy sauce, forget the water, the sauce simmering, or stuffing. Baste the cooked fish with soy sauce and oil and garnish the fish with the sliced onion and Chinese parsley and expect a gourmet's delight.

Few authors consider conservation and Wilson and Vander Werff's fishing ethic should be heeded by all anglers: "Appreciate this resource; take as much as you can reasonably use regardless of legal catch limits. Take care of your catch, and don't waste it. The fish you leave today will be there for your sport tomorrow and for generations of anglers that follow you."

The $4.95 price tag may seem high for a 150 page paperback but don't judge this book by its cover; the value is in its content.—*Tom Jow*

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Photoelectronic composition by
CALIFORNIA OFFICE OF STATE PRINTING

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FISH AND GAME COMMISSION
NOTICE OF MEETINGS RELATIVE TO
1979 SPORT FISHING REGULATIONS

NOTICE IS HEREBY GIVEN that the Fish and Game Commission, pursuant to the authority vested by Sections 200–221 of the Fish and Game Code, will meet on October 6, 1978, at 9:00 a.m. in the Auditorium of the Resources Building, 1416 Ninth Street, Sacramento, California to receive recommendations as to what regulations should be made relating to fish, amphibia and reptiles for 1979.

Notice is also given that the Fish and Game Commission will meet on November 10, 1978, at 9:00 a.m. in the Supervisors' Chambers of the Shasta County Courthouse, Redding, California, for public discussion of and presentations of objections to the proposals presented to the commission on October 6, 1978, and after considering such discussion and objections, the commission shall announce the regulations which it proposes to make relating to fish, amphibia and reptiles.

Notice is also given that the Fish and Game Commission will meet on December 8, 1978 at 9:00 a.m. in Room 1138 of the State Building, 107 S. Broadway, Los Angeles, California to hear and consider any objections to its tentative approvals in relation to fish, amphibia and reptiles for the 1979 sport fishing season.

Environmental plans with respect to the Department's proposals will be on file and available for public review in the commission office, 1416 Ninth Street, Sacramento, California 95814 after October 6, 1978.

The Fish and Game Commission has determined that there are no new costs to local government, pursuant to Section 2231 of the Revenue and Taxation Code.

FISH AND GAME COMMISSION

Leslie F. Edgerton
Executive Secretary